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ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TESTS J4-1801-28 THROUGH J4-1801-33)

C. H. Kunz and H. J. Counts, Jr.

ARO, Inc.

October 1968

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ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TESTS J4-1801-28 THROUGH J4-1801-33)

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FOREWORD

The work reported herein was sponsored by the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC) (I-E-J), under System 921E, Project 9194.

The results of the tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract F40600-69-C-0001. Program direction was provided by NASA/MSFC; engineering liaison was provided by North American Rockwell Corporation, Rocketdyne Division, manufacturer of the J-2 rocket engine, and McDonnell Douglas Corporation, Missile and Space Systems Division, manufacturer of the S-IVB stage. The testing reported herein was conducted on February 15 and 22 and March 1, 8, 14, and 20, 1968, in Propulsion Engine Test Cell (J-4) of the Large Rocket Facility (LRF) under ARO Project No. KA1801. The manuscript was submitted for publication on June 21, 1968.

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This technical report has been reviewed and is approved.

Edgar D. Smith Major, USAF AF Representative, LRF Directorate of Test	Roy R. Croy, Jr. Colonel, USAF Director of Test

ABSTRACT

Twenty-four firings and two fuel lead tests of the Rocketdyne J-2 rocket engine were conducted during test periods J4-1801-28 through J4-1801-33 between February 15 and March 20, 1968, in Test Cell J-4 of the Large Rocket Facility. This testing was in support of the J-2 engine application to the S-II stage of the Saturn V vehicle. The firings were accomplished at pressure altitudes ranging from 55,000 to 116,000 ft at engine start. The primary objective of these firings was to investigate fuel pump operation under conditions of lower than minimum engine model specification fuel pump net positive suction head and maximum thrust chamber fuel flow resistance utilizing an S-II stage center engine configuration fuel low pressure duct designed to simulate the fluid dynamic characteristics experienced during flight. Engine components were thermally conditioned to temperatures as expected during flight. Engine operation appeared to be satisfactory. The total accumulated firing duration for the six test periods was 190 sec. The total firing duration of this engine at AEDC through test period J4-1801-33 is 940 sec, resulting from 79 engine firings.

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I. ILLUSTRATIONS

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NOMENCLATURE

A	Area, in.^{2}
ASI	Augmented spark igniter
ES	Engine start, designated as the time that helium control and ignition phase solenoids are energized
GG	Gas generator
MOV	Main oxidizer valve
NPSH	Net positive suction head, ft
STDV	Start tank discharge valve
t_0	Defined as the time at which the opening signal is applied to the start tank discharge valve solenoid
VSC	Vibration safety counts, defined as the time at which engine vibration was in excess of 150 g rms in a 960- to 6000-Hz frequency range

SUBSCRIPTS

f	Force
m	Mass
t	Throat

SECTION I
INTRODUCTION

Testing of the Rocketdyne J-2 rocket engine using an S-IVB battleship stage has been in progress since July 1966 at AEDC in support of the J-2 engine application on the Saturn IB and Saturn V launch vehicles for the NASA Apollo Program. The 24 engine firings and two fuel lead tests reported herein were conducted during test periods J4-1801-28 through 33 on February 15 and 22 and March 1, 8, 14, and 20, 1968, respectively, in the Propulsion Engine Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Large Rocket Facility (LRF). These firings were to evaluate both the engine and fuel pump start transient performance with (1) lower than minimum engine model specification fuel pump NPSH during the start transient as required on AS-502 and subsequent flights and (2) warmer than maximum expected S-II thrust chamber temperature utilizing a 230,000-lb_f-thrust configuration engine and an S-II stage center engine configured fuel low pressure duct. Test periods J4-1801-28 and 29 were conducted at pressure altitudes of approximately 55,000 ft (facility steam ejector system inoperative), whereas test period 30 and subsequent test periods were conducted at pressure altitudes of approximately 100,000 ft (geometric pressure altitude, Z, Ref. 1) (facility steam ejector system operative) at engine start. Engine components were conditioned to S-II interstage temperatures predicted for flight. Data collected to accomplish the test objectives are presented herein. The results of the previous test period are presented in Ref. 2.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The test article was a J-2 rocket engine (S/N J-2047) (Fig. 3) designed and developed by Rocketdyne Division of North American Rockwell Corporation. The engine uses liquid oxygen and liquid hydrogen as propellants and has a thrust rating of 230,000 lb_f at an oxidizer-to-fuel ratio of 5.5. An S-IVB battleship stage was used to supply propellant to the engine. The fuel low pressure duct was replaced for this series of tests with a special duct (Fig. 4) designed to simulate the fluid dynamic characteristics of the center engine duct of the S-II stage. This duct was designed to decrease the fuel pump inlet total pressure during initial acceleration of fuel by the pump 4.5 psi below the level experienced at t_0 and to experience 1.5-psi friction loss under main-stage flow conditions.

Heat was added to the duct with heater tape, as indicated in Fig. 4, to simulate temperature transient experienced on flight AS-501. A schematic of the battleship stage is presented in Fig. 5.

Listings of major engine components and engine orifices of this test series are presented in Tables I and II, respectively (Appendix II). All engine modifications and component replacements performed since the previous test period are presented in Tables III and IV, respectively.

2.1.1 J-2 Rocket Engine

The J-2 rocket engine (Figs. 3 and 6, Ref. 3) features the following major components:

1. Thrust Chamber - The tubular-walled, bell-shaped thrust chamber consists of an 18.6-in.-diam combustion chamber (8.0 in. long from the injector mounting to the throat inlet) with a characteristic length (L*) of 24.6 in., a 170.4-in.^{2} throat area, and a divergent nozzle with an expansion ratio of 27.1. Thrust chamber length (from the injector flange to the nozzle exit) is 107 in. Cooling is accomplished by the circulation of engine fuel flow downward from the fuel manifold through 180 tubes and then upward through 360 tubes to the injector.

2. Thrust Chamber Injector - The injector is a concentric-orificed (concentric fuel orifices around the oxidizer post orifices), porous-faced injector. Fuel and oxidizer injector orifice areas are 25.0 and 16.0 in.^{2}, respectively. The porous material, forming the injector face, allows approximately 3.5 percent of total fuel flow to transpiration cool the face of the injector.

3. Augmented Spark Igniter - The augmented spark igniter unit is mounted on the thrust chamber injector and supplies the initial energy source to ignite propellants in the main combustion chamber. The augmented spark igniter chamber is an integral part of the thrust chamber injector. Fuel and oxidizer are ignited in the combustion area by two spark plugs.

4. Fuel Turbopump - The turbopump is composed of a two-stage turbine-stator assembly, an inducer, and a seven-stage axial-flow pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 38,215 ft (1248 psia) of liquid hydrogen at a flow rate of 8585 gpm for a rotor speed of 27,265 rpm.

5. Oxidizer Turbopump - The turbopump is composed of a two-stage turbine-stator assembly and a single-stage centrifugal

pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 2170 ft (1107 psia) of liquid oxygen at a flow rate of 2965 gpm for a rotor speed of 8688 rpm.

6. Gas Generator - The gas generator consists of a combustion chamber containing two spark plugs, a pneumatically operated control valve containing oxidizer and fuel poppets, and an injector assembly. The oxidizer and fuel poppets provide a fuel lead to the gas generator combustion chamber. The high energy gases produced by the gas generator are directed to the fuel turbine and then to the oxidizer turbine (through the turbine crossover duct) before being exhausted into the thrust chamber at an area ratio (A/A_t) of approximately 11.

7. Propellant Utilization Valve - The motor-driven propellant utilization valve is mounted on the oxidizer turbopump and bypasses liquid oxygen from the discharge to the inlet side of the pump to vary engine mixture ratio.

8. Propellant Bleed Valves - The pneumatically operated fuel and oxidizer bleed valves provide pressure relief for the boiloff of propellants trapped between the battleship stage prevalves and main propellant valves at engine shutdown.

9. Integral Hydrogen Start Tank and Helium Tank - The integral tanks consist of a 7258-in.^{3} sphere for hydrogen with a 1000-in.^{3} sphere for helium located within it. Pressurized gaseous hydrogen in the start tank provides the initial energy source for spinning the propellant turbopumps during engine start. The helium tank provides a helium pressure supply to the engine pneumatic control system.

10. Oxidizer Turbine Bypass Valve - The pneumatically actuated oxidizer turbine bypass valve provides control of the fuel turbine exhaust gases directed to the oxidizer turbine in order to control the oxidizer-to-fuel turbine spinup relationship. The fuel turbine exhaust gases which bypass the oxidizer turbine are discharged into the thrust chamber.

11. Main Oxidizer Valve - The main oxidizer valve is a pneumatically actuated, two-stage, butterfly-type valve located in the oxidizer high pressure duct between the turbopump and the main injector. The first-stage actuator positions the main oxidizer valve at the 14-deg position to obtain initial thrust chamber ignition; the second-stage actuator ramps the main oxidizer valve full open to accelerate the engine to main-stage operation.

12. Main Fuel Valve - The main fuel valve is a pneumatically actuated butterfly-type valve located in the fuel high pressure duct between the turbopump and the fuel manifold.
13. Pneumatic Control Package - The pneumatic control package controls all pneumatically operated engine valves and purges.
14. Electrical Control Assembly - The electrical control assembly provides the electrical logic required for proper sequencing of engine components during operation.
15. Primary and Auxiliary Flight Instrumentation Packages - The instrumentation packages contain sensors required to monitor critical engine parameters. The packages provide environmental control for the sensors.

2.1.2 S-IVB Battleship Stage

The S-IVB battleship stage is approximately 22 ft in diameter and 49 ft long and has a maximum propellant capacity of 46, 000 lb of liquid hydrogen and 199, 000 lb of liquid oxygen. The propellant tanks, fuel above oxidizer, are separated by a common bulkhead. Propellant prevalves, in the low pressure ducts (external to the tanks) interfacing the stage and the engine, retain propellant in the stage until being admitted into the engine to the main propellant valves and serve as emergency engine shutoff valves. Propellant recirculation pumps in both fuel and oxidizer tanks are utilized to circulate propellants through the low pressure ducts and turbopumps before engine start to stabilize hardware temperatures near normal operating levels and to prevent propellant temperature stratification. Vent and relief valve systems are provided for both propellant tanks.

Pressurization of the fuel and oxidizer tanks was accomplished by facility systems using hydrogen and helium, respectively, as the pressurizing gases. The engine-supplied gaseous hydrogen and gaseous oxygen for fuel and oxidizer tank pressurization during S-II flight were routed to the respective facility venting systems.

2.2 TEST CELL

Test Cell J-4, Fig. 2, is a vertically oriented test unit designed for static testing of liquid-propellant rocket engines and propulsion systems at pressure altitudes of 100, 000 ft. The basic cell construction provides a 1.5-million-lb_f-thrust capacity. The cell consists of four major components (1) test capsule, 48 ft in diameter and 82 ft in height,

situated at grade level and containing the test article; (2) spray chamber, 100 ft in diameter and 250 ft in depth, located directly beneath the test capsule to provide exhaust gas cooling and dehumidification; (3) coolant water, steam, nitrogen (gaseous and liquid), hydrogen (gaseous and liquid), and liquid oxygen and gaseous helium storage and delivery systems for operation of the cell and test article; and (4) control building, containing test article controls, test cell controls, and data acquisition equipment. Exhaust machinery is connected with the spray chamber and maintains a minimum test cell pressure before and after the engine firing and exhausts the products of combustion from the engine firing. Before a firing, the facility steam ejector, in series with the exhaust machinery, provides a pressure altitude of 100,000 ft in the test capsule. A detailed description of the test cell is presented in Ref. 4.

The battleship stage and the J-2 engine were oriented vertically downward on the centerline of the diffuser-steam ejector assembly. This assembly consisted of a diffuser duct (20 ft in diameter by 150 ft in length), a centerbody steam ejector within the diffuser duct, a diffuser insert (13.5 ft in diameter by 30 ft in length) at the inlet to the diffuser duct, and a gaseous nitrogen annular ejector above the diffuser insert. The diffuser insert was provided for dynamic pressure recovery of the engine exhaust gases and to maintain engine ambient pressure altitude (attained by the steam ejector) during the engine firing. The annular ejector was provided to suppress steam recirculation into the test capsule during steam ejector shutdown. The test cell was also equipped with (1) a gaseous nitrogen purge system for continuously inerting the normal air in-leakage of the cell; (2) a gaseous nitrogen repressurization system for raising test cell pressure, after engine cutoff, to a level equal to spray chamber pressure and for rapid emergency inerting of the capsule; and (3) a spray chamber liquid nitrogen supply and distribution manifold for initially inerting the spray chamber and exhaust ducting and for increasing the molecular weight of the hydrogen-rich exhaust products.

An engine component conditioning system was provided for temperature conditioning engine components. The conditioning system utilized a liquid hydrogen-helium heat exchanger to provide cold helium gas for component conditioning. Components requiring temperature conditioning were the thrust chamber, turbine components, start tank discharge valve, gas generator control valve (tests 31 and 32 only), main oxidizer valve second-stage actuator, and fuel low pressure duct. Helium was routed internally through the crossover duct and tubular-walled thrust chamber and externally over the start tank discharge valve and gas generator control valve. The main oxidizer valve second-stage actuator was conditioned by admitting propellants into the engine. The

fuel low pressure duct was thermally conditioned utilizing the heater tape as shown in Fig. 4.

2.3 INSTRUMENTATION

Instrumentation systems were provided to measure engine, stage, and facility parameters. The engine instrumentation was comprised of (1) flight instrumentation for the measurement of critical engine parameters and (2) facility instrumentation which was provided to verify the flight instrumentation and to measure additional engine parameters. The flight instrumentation was provided and calibrated by the engine manufacturer; facility instrumentation was initially calibrated and periodically recalibrated at AEDC. Appendix III contains a list of all measured test parameters and the locations of selected sensing points.

Pressure measurements were made using strain-gage-type pressure transducers. Temperature measurements were made using resistance temperature transducers and thermocouples. Oxidizer and fuel turbopump shaft speeds were sensed by magnetic pickup. Fuel and oxidizer flow rates to the engine were measured by turbine-type flowmeters which are an integral part of the engine. The propellant recirculation flow rates were also monitored with turbine-type flowmeters. Vibrations were measured by accelerometers mounted on the oxidizer injector dome and on the turbopumps. Primary engine and stage valves were instrumented with linear potentiometers and limit switches.

The data acquisition systems were calibrated by (1) precision electrical shunt resistance substitution for the pressure transducers and resistance temperature transducer units; (2) voltage substitution for the thermocouples; (3) frequency substitution for shaft speeds and flowmeters; and (4) frequency-voltage substitution for accelerometers.

The types of data acquisition and recording systems used during this test period were (1) a multiple-input digital data acquisition system (MicroSADIC®) scanning each parameter at 40 samples per second and recording on magnetic tape, (2) single-input, continuous-recording FM systems recording on magnetic tape, (3) photographically recording galvanometer oscillographs, (4) direct-inking, null-balance potentiometer-type X-Y plotters and strip charts, and (5) optical data recorders. Applicable systems were calibrated before each test (atmospheric and altitude calibrations). Television cameras, in conjunction with video tape recorders, were used to provide visual coverage during an engine firing, as well as for replay capability for immediate examination of unexpected events.

2.4 CONTROLS

Control of the J-2 engine, battleship stage, and test cell systems during the terminal countdown was provided from the test cell control room. A facility control logic network was provided to interconnect the engine control system, major stage systems, the engine safety cutoff system, the observer cutoff circuits, and the countdown sequencer. A schematic of the engine start control logic is presented in Fig. 7. The sequence of engine events for a normal start and shutdown is presented in Figs. 8a and b. Two control logics for sequencing the stage prevalves and recirculation systems with engine start for simulating engine flight start sequences are presented in Figs. 8c and d.

SECTION III
PROCEDURE

Preoperational procedures were begun several hours before the test period. All consumable storage systems were replenished, and engine inspections, leak checks, and drying procedures were conducted. Propellant tank pressurants and engine pneumatic and purge gas samples were taken to ensure that specification requirements were met. Chemical analysis of propellants was provided by the propellant suppliers. Facility sequence, engine sequence, and engine abort checks were conducted within a 24-hr time period before an engine firing to verify the proper sequence of events. Facility and engine sequence checks consisted of verifying the timing of valves and events to be within specified limits; the abort checks consisted of electrically simulating engine malfunctions to verify the occurrence of an automatic engine cutoff signal. A final engine sequence check was conducted immediately preceding the test period.

Oxidizer dome, gas generator oxidizer injector, and thrust chamber jacket purges were initiated before evacuating the test cell. After completion of instrumentation calibrations at atmospheric conditions, the test cell was evacuated to approximately 0.5 psia with the exhaust machinery, and instrumentation calibrations at altitude conditions were conducted. Immediately before loading propellants on board the vehicle, the cell and exhaust-ducting atmosphere was inerted. At this same time, the cell nitrogen purge was initiated for the duration of the test period, except for the engine firing. The vehicle propellant tanks were then loaded, and the remainder of the terminal countdown was conducted. Temperature conditioning of the various engine components was accomplished as required, using the facility-supplied engine component conditioning

system. Components which required temperature conditioning were the thrust chamber, the turbine start tank discharge valve, gas generator control valve (tests 31 and 32), main oxidizer valve second-stage actuator, and fuel low pressure duct. Table V presents the engine purges and thermal conditioning operations during the terminal countdown and immediately following the engine firing.

SECTION IV
RESULTS AND DISCUSSION

4.1 TEST SUMMARY

4.1.1 General

Twenty-four firings and two fuel lead tests of the J-2 rocket engine (S/N J-2047) were conducted during test periods J4-1801-28 through J4-1801-33 for a total firing duration of 190 sec. The total accumulated firing duration for this engine at AEDC through test period J4-1801-33 (March 20, 1968) is 936 sec.

The principle objectives of these test periods were to evaluate both the engine and fuel pump start transient performance with (1) lower than minimum engine model specification fuel pump NPSH during the start transient as required on AS-502 and subsequent flights and with (2) warmer than maximum expected S-II stage thrust chamber temperatures. Other engine components were thermally conditioned to temperatures as expected and/or observed on flight AS-501.

A special duct designed to simulate the fluid dynamic characteristics of the S-II stage center engine low pressure fuel duct was utilized for this test series. This duct was designed to decrease the fuel pump inlet total pressure during initial acceleration of fuel by the pump 4.5 psi below the level experienced at t_0 and to experience a 1.5-psi friction loss with main-stage flow conditions. Test data indicate actual pressure drop during acceleration of fuel was 4.6 psi, and friction losses resulting from main-stage flow conditions were calculated to be 1.6 psi.

Firing 29B and all subsequent firings of this series were conducted with below minimum model specification fuel pump NPSH during the starting transient (Ref. 5). Engine operation under these conditions was satisfactory except for firing 29D, which resulted in a premature engine cutoff by the engine safety cutoff system because of an excessive gas generator outlet temperature initial peak of 2460°F. For this firing,

the fuel pump inlet pressure dropped below vapor pressure for 120 msec during the starting transient. Fuel pump inlet pressure targets for test periods subsequent to test 29 were extended to provide an additional 15 ft of NPSH at engine start.

Thirteen engine firings were conducted with thrust chamber temperatures at engine start ranging from -114 to +46°F, which is warmer than expected for flight with present launch redline limits. All of these firings conducted with thrust chamber temperature warmer than -65°F exhibited insufficient stall margin. Firing 32D conducted with an average thrust chamber temperature of -91°F at engine start experienced a low level stall margin of 90 gpm; however, this firing was prematurely terminated at t_0 + 0.661 sec by a valid cutoff signal from the stall approach monitor. This is a safety cutoff (not part of the engine safety cutoff system) which will terminate a firing if fuel flow is below 3200 gpm for any 55-msec period after t_0 + 0.585 sec.

The facility steam ejector system was inoperative for test periods J4-1801-28 and J4-1801-29; therefore, these tests were conducted at pressure altitudes of approximately 55,000 ft. This system was operative on subsequent test periods which experienced pressure altitudes of approximately 100,000 ft at engine start.

Test requirements and specific test results are summarized in Table VI. Start and shutdown transient operating times for selected engine valves are shown in Table VII. Calculated engine steady-state performance data are shown in Table VIII. Methods of calculations are shown in Appendix IV. Figure 9 shows engine start conditions for pump inlets and the hydrogen start tank for all firings. Specific test objectives and a brief summary of results obtained for each firing are presented in the following sections.

4.1.2 Test J4-1801-28A

4.1.2.1 Objectives

Conduct an 8-sec fuel lead test to be terminated at t_0 to establish fuel low pressure duct (1) integrity with low fuel flow, (2) temperature transients experienced during the fuel lead, and (3) pressure transients resulting from closure of the main fuel valve.

4.1.2.2 Results

The fuel lead test was successfully accomplished, and all test objectives were obtained. The fuel low pressure duct integrity was

satisfactory under these test conditions. Thermal conditioning history of the thrust chamber is shown in Fig. 10. Engine ambient pressure experienced during the test is shown in Fig. 11. Fuel low pressure duct temperature and pressure transients experienced during the test are presented in Fig. 12.

4.1.3 Test J4-1801-28B

4.1.3.1 Objectives

Conduct an 8-sec fuel lead test (repeat of test 28A) to be terminated at t_0 to further establish fuel low pressure duct (1) integrity with low fuel flow, (2) temperature transients experienced during the fuel lead, and (3) pressure transients resulting from closure of the main fuel valve.

4.1.3.2 Results

The fuel lead test was successfully accomplished, and all objectives were obtained. The fuel low pressure duct integrity was found to be satisfactory under these test conditions. Thermal conditioning history of the thrust chamber is presented in Fig. 13. Engine ambient pressure experienced during the test is presented in Fig. 14. Fuel low pressure duct pressure and temperature transients experienced during the test are shown in Fig. 15.

4.1.4 Firing J4-1801-28C

4.1.4.1 Objectives

Conduct a 0.550-sec engine firing to evaluate fuel low pressure duct integrity.

4.1.4.2 Results

The firing was successfully accomplished, and all test objectives were obtained. The fuel low pressure duct integrity was found to be satisfactory. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are presented in Figs. 16 through 18, respectively. Fuel low pressure duct pressure and temperature transients experienced during the firing are shown in Fig. 19.

4.1.5 Firing J4-1801-29A

4.1.5.1 Objectives

Conduct a 7.5-sec engine firing to determine fuel low pressure duct friction losses during engine main-stage operation and magnitude of fuel pump inlet pressure drop during initial acceleration of fuel by the pump, with approximately 60 percent of maximum engine model specification fuel pump NPSH (1068 ft) at engine start.

4.1.5.2 Results

The firing was successfully accomplished, and all test objectives were obtained. Fuel low pressure duct friction losses during main stage were calculated to be approximately 1.6 psi (difference in total pressure between fuel tank ullage and fuel pump inlet). Fuel pump inlet pressure decreased 4.6 psi during initial acceleration of fuel by the pump. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are presented in Figs. 20 through 22, respectively. Fuel pump start transient head/flow data are shown in Fig. 23. Fuel low pressure duct temperature and pressure transients experienced during the firing and fuel pump NPSH are shown in Fig. 24.

4.1.6 Firing J4-1801-29B

4.1.6.1 Objectives

Conduct a 7.5-sec firing to evaluate the engine starting transient and fuel pump operation with -240°F and 1400-psia start tank gas conditions (high starting energy), -275°F thrust chamber temperature, and fuel pump NPSH of 110 ft at engine start.

4.1.6.2 Results

The firing was successfully accomplished, and all test objectives were obtained. The engine starting transient and fuel pump operation under these test conditions were satisfactory. Fuel pump inlet pressure dropped below vapor pressure for 25 msec during initial acceleration of fuel by the pump. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are presented in Figs. 25 through 27, respectively. Fuel pump start transient head/flow data are shown in Fig. 28. Fuel low pressure duct temperature

and pressure transients experienced during the firing and fuel pump NPSH are shown in Fig. 29.

4.1.7 Firing J4-1801-29C

4.1.7.1 Objectives

Conduct a 7.5-sec firing to evaluate engine starting transients and fuel pump operation with -240°F and 1400-psia start tank gas conditions (high starting energy), -150°F thrust chamber temperature, and fuel pump NPSH of 110 ft at engine start.

4.1.7.2 Results

The firing was successfully accomplished, and all test objectives were obtained. The engine starting transient and fuel pump operation under these test conditions were satisfactory. Fuel pump inlet pressure dropped below vapor pressure for 100 msec during initial acceleration of fuel by the pump. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are presented in Figs. 30 through 32, respectively. Fuel pump start transient head/flow data are shown in Fig. 33. Fuel low pressure duct temperature and pressure transients experienced during the firing and fuel pump NPSH are shown in Fig. 34.

4.1.8 Firing J4-1801-29D

4.1.8.1 Objectives

Conduct a 7.5-sec firing to evaluate the engine starting transient and fuel pump operation with -300°F and 1300-psia start tank gas conditions (high starting energy), -275°F thrust chamber temperature, and fuel pump NPSH of 110 ft at engine start.

4.1.8.2 Results

All starting conditions were within starting targets; however, the firing was prematurely terminated by the engine safety cutoff system at t_0 + 1.1 sec because of an excessive gas generator outlet temperature initial peak of 2460°F. Fuel pump inlet pressure dropped below vapor pressure for 120 msec during initial acceleration of the fuel by the pump. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are presented in Figs. 35 through 37,

respectively. Fuel pump start transient head/flow data are shown in Fig. 38. Fuel low pressure duct temperature and pressure transients experienced during the firing and fuel pump NPSH are shown in Fig. 39.

4.1.9 Firing J4-1801-29E

4.1.9.1 Objectives

Conduct a 7.5-sec firing to evaluate the engine starting transient and fuel pump operation with -300°F and 1300-psia start tank gas conditions (high starting energy), -150°F thrust chamber temperature, and fuel pump NPSH of 110 ft at engine start.

4.1.9.2 Results

The engine firing was successfully accomplished, and all test objectives were obtained. The engine starting transient and fuel pump operation under these conditions were satisfactory. Fuel pump inlet pressure dropped below vapor pressure for 25 msec during initial acceleration of fuel by the pump. Thermal conditioning history of engine components, engine ambient and combustion chamber pressure experienced during the firing, and engine start and shutdown transients are presented in Figs. 40 through 42, respectively. Fuel pump start transient head/flow data are shown in Fig. 43. Fuel low pressure duct pressure and temperature transients experienced during the firing and fuel pump NPSH are shown in Fig. 44.

4.1.10 Firing J4-1801-30A

4.1.10.1 Objectives

Conduct a 7.5-sec firing to evaluate engine buildup time and fuel pump stall margin with -140°F and 1250-psia start tank conditions (low starting energy), -275°F thrust chamber temperature, and fuel pump NPSH of 125 ft at engine start.

4.1.10.2 Results

The firing was successfully accomplished, and all test objectives were obtained. Main-stage operation was attained at t_0 + 2.192 sec (as indicated by the time at which chamber pressure attained 550 psia). The fuel pump minimum high level stall margin was 250 gpm. This is the smallest high level stall margin noted to date at AEDC. Fuel pump NPSH dropped to 20 ft during initial acceleration of fuel by the pump. Thermal conditioning history of engine components, engine ambient and

combustion chamber pressures experienced during the firing, and engine start and shutdown transients are presented in Figs. 45 through 47, respectively. Fuel pump start transient head/flow data are shown in Fig. 48. Fuel low pressure duct temperature and pressure transients experienced during the firing and fuel pump NPSH are shown in Fig. 49.

4.1.11 Firing J4-1801-31A

4.1.11.1 Objectives

Conduct a 32.5-sec firing to evaluate engine buildup time and fuel pump high level stall margin with -300°F and 1300-psia start tank gas conditions (high starting energy), -275°F thrust chamber temperature, and fuel pump NPSH of 125 ft at engine start.

4.1.11.2 Results

The engine firing was successfully accomplished, and all primary test objectives were obtained. Power was not supplied to the propellant utilization valve control panel; therefore the desired mixture ratio change could not be accomplished. The valve remained in the desired position during the start transient. Main-stage operation was attained at t_0 + 2.004 sec. Fuel pump high level stall margin was 550 gpm. Fuel pump NPSH dropped to 40 ft during initial acceleration of fuel by the pump. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are presented in Figs. 50 through 52, respectively. Fuel pump start transient head/flow data are shown in Fig. 53. Fuel low pressure duct pressure and temperature transients experienced during the firing and fuel pump NPSH are shown in Fig. 54.

4.1.12 Firing J4-1801-31B

4.1.12.1 Objectives

Conduct a 32.5-sec firing to evaluate the engine starting transient and fuel pump operation with -200°F and 1200-psia start tank gas conditions (low starting energy), -275°F thrust chamber temperature, and fuel pump NPSH of 125 ft at engine start.

4.1.12.2 Results

The firing was successfully accomplished, and all test objectives were obtained. The engine starting transient and fuel pump performance

under these conditions were satisfactory. Fuel pump NPSH dropped to 40 ft during initial acceleration of the fuel by the pump. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are shown in Figs. 55 through 57, respectively. Engine steady-state performance data are shown in Table VIII. Fuel pump start transient head/flow data are shown in Fig. 58. Fuel low pressure duct temperature and pressure transients experienced during the firing and fuel pump NPSH are shown in Fig. 59.

Abnormal chilldown of turbine hardware after firing 31B resulted from a leaking gas generator fuel poppet. Therefore, test requirements for subsequent firings were revised to prevent gas generator ignition by selecting a run duration of 0.600 sec. Also, because of this leak, the fuel turbine discharge conditioning temperature (TFTD-2) could not be maintained within the desired limits.

4.1.13 Firing J4-1801-31C

4.1.13.1 Objectives

Conduct a 0.600-sec partial transition firing to evaluate fuel pump low level stall margin with +50°F thrust chamber temperature, 1400-psia and -240°F start tank gas conditions, and fuel pump NPSH of 125 ft at engine start.

4.1.13.2 Results

The partial transition firing was successfully accomplished, and the test objective was obtained. Fuel pump head/flow conditions became such that the stall region was entered at t_0 + 0.52 sec. No indication of pump recovery was observed. The fuel turbine discharge conditioning temperature (TFTD-2) could not be maintained within desired target limits because of a gas generator fuel poppet leak. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are presented in Figs. 60 through 62, respectively. Fuel pump start transient head/flow data are shown in Fig. 63. Fuel low pressure duct temperature, pressure transients experienced during the firing, and fuel pump NPSH are shown in Fig. 64.

4.1.14 Firings J4-1801-31D

4.1.14.1 Objectives

Conduct a 0.600-sec partial transition firing to evaluate fuel pump low level stall margin with 0°F thrust chamber temperature, 1400-psia and -240°F start tank gas conditions, and fuel pump NPSH of 125 ft at engine start.

4.1.14.2 Results

The partial transition firing was successfully accomplished, and the test objective was obtained. Fuel pump head/flow conditions became such that the stall region was entered at t_0 + 0.52 sec. No indication of pump recovery was observed. The fuel turbine discharge conditioning temperature (TFTD-2) could not be maintained within desired target limits because of a gas generator fuel poppet leak. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are presented in Figs. 65 through 67, respectively. Fuel pump start transient head/flow data are shown in Fig. 68. Fuel low pressure duct temperature and pressure transients experienced during the firing and fuel pump NPSH are presented in Fig. 69.

4.1.15 Firing J4-1801-31E

4.1.15.1 Objectives

Conduct a 0.600-sec partial transition firing to evaluate fuel pump low level stall margin at a -50°F thrust chamber temperature, 1400-psia and -240°F start tank gas conditions, and fuel pump NPSH of 125 ft at engine start.

4.1.15.2 Results

The firing was successfully accomplished, and the objective was obtained. Fuel pump start transient head/flow conditions were such that the stall region was entered by 150 gpm when cutoff occurred. Flow had increased approximately 1000 gpm before the main fuel valve began to close. The fuel turbine discharge conditioning temperature (TFTD-2) could not be maintained within desired target limits because of a gas generator fuel poppet leak. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are shown in Figs. 70 through 72, respectively. Fuel pump start transient

head/flow data are shown in Fig. 73. Fuel low pressure duct temperature and pressure transients experienced during the firing and fuel pump NPSH are shown in Fig. 74.

4.1.16 Firing J4-1801-32A

4.1.16.1 Objectives

Conduct a 7.5-sec firing to evaluate thrust chamber pressure buildup time and fuel pump high level stall margin utilizing -300°F and 1200-psia start tank gas conditions, -275°F thrust chamber temperature, and fuel pump NPSH of 125 ft at engine start.

4.1.16.2 Results

The firing was successfully accomplished, and all objectives were obtained. Engine main-stage operation was attained at t_0 + 2.031 sec. Fuel pump high level stall margin was 500 gpm. Fuel pump inlet pressure dropped below vapor pressure for 25 msec during initial acceleration of the fuel by the pump. Fuel pump operation appeared satisfactory. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are shown in Figs. 75 through 77, respectively. Fuel pump start transient head/flow data are shown in Fig. 78. Fuel low pressure duct temperature and pressure transients experienced during the firing and fuel pump NPSH are shown in Fig. 79.

4.1.17 Firing J4-1801-32B

4.1.17.1 Objectives

Conduct a 7.5-sec firing to evaluate thrust chamber pressure buildup time and fuel pump high level stall margin utilizing -300°F and 1300-psia start tank gas conditions, -275°F thrust chamber temperature, and fuel pump NPSH of 125 ft at engine start.

4.1.17.2 Results

The firing was successfully accomplished, and all objectives were obtained. Engine main-stage operation was attained at t_0 + 2.058 sec. Fuel pump high level stall margin was 750 gpm. Fuel pump inlet pressure dropped to vapor pressure during initial acceleration of the fuel by the pump. Pump operation appeared satisfactory. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and

shutdown transients are shown in Figs. 80 through 82, respectively. Fuel pump start transient head/flow data are shown in Fig. 83. Fuel low pressure duct pressure and temperature transients experienced during the firing and fuel pump NPSH are presented in Fig. 84.

4.1.18 Firing J4-1801-32C

4.1.18.1 Objectives

Conduct a 1.150-sec partial transition firing to determine fuel pump start transient characteristics utilizing a -75°F thrust chamber temperature, -240°F and 1400-psia start tank gas conditions, and fuel pump NPSH of 125 ft at engine start.

4.1.18.2 Results

The firing was successfully accomplished, and the objective was obtained. Fuel pump low level stall margin was 650 gpm. Fuel pump inlet pressure dropped below vapor pressure for 75 msec during initial acceleration of the fuel by the pump. Pump operation appeared satisfactory. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are shown in Figs. 85 through 87, respectively. Fuel pump start transient head/flow data are shown in Fig. 88. Fuel low pressure duct temperature and pressure transients experienced during the firing and fuel pump NPSH are shown in Fig. 89.

4.1.19 Firing J4-1801-32D

4.1.19.1 Objectives

Conduct a 1.150-sec partial transition firing to determine fuel pump start transient characteristics utilizing a -75°F thrust chamber temperature, -200°F and 1200-psia start tank gas conditions, and fuel pump NPSH of 125 ft at engine start.

4.1.19.2 Results

The firing was prematurely terminated at t_0 + 0.669 sec by the stall approach monitor. This is a safety cutoff system which will terminate a firing if fuel flow is below 3200 gpm for any 55-msec period after t_0 + 0.585 sec. All starting conditions were within the required target limits. Minimum fuel pump low level stall margin occurred at t_0 + 0.600 sec and was 90 gpm. Fuel pump NPSH dropped to 5 ft during initial acceleration of the fuel by the pump. Thermal conditioning history

of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are shown in Figs. 90 through 92, respectively. Fuel pump start transient head/flow data are shown in Fig. 93. Fuel low pressure duct pressure and temperature transients experienced during the firing and fuel pump NPSH are presented in Fig. 94.

4.1.20 Firing J4-1801-32E

4.1.20.1 Objectives

Conduct a 1.150-sec partial transition firing to determine fuel pump start transient characteristics utilizing a -100°F thrust chamber temperature, -200°F and 1200-psia start tank gas conditions, and fuel pump NPSH of 125 ft at engine start.

4.1.20.2 Results

The firing was successfully accomplished, and the objective was obtained. Minimum fuel pump low level stall margin was 550 gpm. Fuel pump inlet pressure dropped below vapor pressure for 100 msec during initial acceleration of the fuel by the pump. Pump operation appeared satisfactory. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are shown in Figs. 95 through 97, respectively. Fuel pump start transient head/flow data are shown in Fig. 98. Fuel low pressure duct pressure and temperature transients experienced during the firing and fuel pump NPSH are presented in Fig. 99.

4.1.21 Firing J4-1801-32F

4.1.21.1 Objectives

Conduct a 1.150-sec partial transition firing to determine fuel pump start transient characteristics utilizing a -85°F thrust chamber temperature, -300°F and 1200-psia start tank gas conditions, and fuel pump NPSH of 125 ft at engine start.

4.1.21.2 Results

The firing was successfully accomplished, and the objective was obtained. Fuel pump operation was essentially the same during both firings 32E and 32F. Minimum fuel pump low level stall margin was 550 gpm. Fuel pump inlet pressure dropped below vapor pressure for

100 msec during initial acceleration of the fuel by the pump. Pump operation appeared satisfactory. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are shown in Figs. 100 through 102, respectively. Fuel pump start transient head/flow data are shown in Fig. 103. Fuel low pressure duct pressure and temperature transients experienced during the firing and fuel pump NPSH are presented in Fig. 104.

4.1.22 Firing J4-1801-32G

4.1.22.1 Objectives

Conduct a 1.150-sec partial transition firing to determine fuel pump start transient characteristics utilizing -300°F and 1300-psia start tank gas conditions, -85°F thrust chamber temperature, and fuel pump NPSH of 125 ft at engine start.

4.1.22.2 Results

The firing was successfully accomplished, and the objective was obtained. Fuel pump low level stall margin was 630 gpm. Fuel pump inlet pressure dropped below vapor pressure for 75 msec during initial acceleration of the fuel by the pump. Pump operation appeared satisfactory. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are shown in Figs. 105 through 107, respectively. Fuel pump start transient head/flow data are shown in Fig. 108. Fuel low pressure duct temperature and pressure transients experienced during the firing and fuel pump NPSH are presented in Fig. 109.

4.1.23 Firing J4-1801-33A

4.1.23.1 Objectives

Conduct a 32.5-sec firing to evaluate the effect of thrust chamber temperature on fuel pump start transient performance utilizing a -100°F thrust chamber temperature, -200°F and 1200-psia start tank gas conditions, and fuel pump NPSH of 125 ft at engine start.

4.1.23.2 Results

The firing was successfully accomplished, and the objective was obtained. Fuel pump operation was satisfactory. Low level stall

margin was 400 gpm. Fuel pump inlet pressure dropped below vapor pressure for 100 msec during initial acceleration of the fuel by the pump. Pump operation was satisfactory. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are shown in Figs. 110 through 112, respectively. Fuel pump start transient head/flow data are shown in Fig. 113. Fuel low pressure duct temperature and pressure transients experienced during the firing and fuel pump NPSH are shown in Fig. 114. Engine steady-state performance data are shown in Table VIII.

4.1.24 Firing J4-1801-33B

4.1.24.1 Objectives

Conduct a 7.5-sec firing to evaluate the effect of thrust chamber temperature on fuel pump start transient performance utilizing a -100°F thrust chamber temperature, -300°F and 1300-psia start tank gas conditions, and fuel pump NPSH of 125 ft at engine start.

4.1.24.2 Results

The firing was successfully accomplished, and the objective was obtained. Fuel pump operation was satisfactory. Fuel pump low level stall margin was 650 gpm. Fuel pump NPSH dropped to 15 ft during initial acceleration of the fuel by the pump. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are shown in Figs. 115 through 117, respectively. Fuel pump start transient head/flow data are shown in Fig. 118. Fuel low pressure duct pressure and temperature transients experienced during the firing and fuel pump NPSH are presented in Fig. 119.

4.1.25 Firing J4-1801-33C

4.1.25.1 Objectives

Conduct a 7.5-sec firing to evaluate the effect of thrust chamber temperature on fuel pump start transient performance utilizing -100°F thrust chamber temperature, -240°F and 1400-psia start tank gas conditions, and fuel pump NPSH of 125 ft at engine start.

4.1.25.2 Results

The firing was successfully accomplished, and the objective was obtained. Fuel pump operation was satisfactory. Fuel pump low level

stall margin was 725 gpm. Fuel pump inlet pressure dropped below vapor pressure for 75 msec during initial acceleration of the fuel by the pump. Pump operation was satisfactory. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are shown in Figs. 120 through 122, respectively. Fuel pump start transient head/flow data are shown in Fig. 123. Fuel low pressure duct pressure and temperature transients experienced during the firing and fuel pump NPSH are presented in Fig. 124.

4.1.26 Firing J4-1801-33D

4.1.26.1 Objectives

Conduct a 7.5-sec firing to evaluate the effect of thrust chamber temperature on fuel pump start transient performance utilizing -100°F thrust chamber temperature, -140°F and 1250-psia start tank gas conditions, and fuel pump NPSH of 125 ft at engine start.

4.1.26.2 Results

The firing was successfully accomplished, and the objective was obtained. Fuel pump operation was satisfactory. Fuel pump low level stall margin was 550 gpm. Fuel pump NPSH dropped to 15 ft during initial acceleration of the fuel by the pump. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are shown in Figs. 125 through 127, respectively. Fuel pump start transient head/flow data are shown in Fig. 128. Fuel low pressure duct temperature and pressure transients experienced during the firing and fuel pump NPSH are shown in Fig. 129.

4.1.27 Firing J4-1801-33E

4.1.27.1 Objectives

Conduct a 7.5-sec firing to evaluate the effect of thrust chamber temperature on fuel pump start transient performance utilizing -100°F thrust chamber temperature, -300°F and 1200-psia start tank conditions, and fuel pump NPSH of 125 ft at engine start.

4.1.27.2 Results

The firing was successfully accomplished, and the objective was obtained. Fuel pump operation was satisfactory. Fuel pump low level

stall margin was 400 gpm. Fuel pump inlet pressure dropped below vapor pressure for 50 msec during initial acceleration of the fuel by the pump. Pump operation was satisfactory. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are shown in Figs. 130 through 132, respectively. Fuel pump start transient head/flow data are shown in Fig. 133. Fuel low pressure temperatures and pressure transients experienced during the firing and fuel pump NPSH are presented in Fig. 134.

4.2 START TRANSIENT INVESTIGATION OF THE EFFECTS OF FUEL PUMP NPSH

The need to reduce fuel pump inlet pressure limits from 28 psia (present minimum model specification) to 27 psia at engine start, as a result of structural problems determined to affect the S-II stage fuel tank on vehicles AS-502, AS-503, and AS-504, justified testing of the J-2 engine with reduced fuel pump inlet pressures at AEDC. Firings of this test series subsequent to firing 29A were conducted at inlet pressures of approximately 26.0 psia.

Data from flight AS-501 indicated the maximum differential temperature between the S-II stage fuel tank bulk and any J-2 engine fuel pump inlet at engine start was 1.2°F. Each degree of temperature differential results in an effective loss of 3.3 psi (110 ft of NPSH). Since data indicated only 0.7°F temperature differential was realized during the integrity check of the low pressure fuel duct during test period J4-1801-28, heat was added to the duct (reference Section 2.1) on subsequent test periods, and temperature differentials as high as 1.8°F at engine start were obtained.

Firings of this test series were successfully accomplished with (1) NPSH as low as 70 ft at engine start (80 ft below minimum model specifications) as a result of reducing fuel pump inlet pressure to approximately 26.0 psia (2 psi lower than minimum model specifications and 1 psi lower than minimum expected on flights AS-502, AS-503, and AS-504) and (2) differential temperatures between the fuel tank bulk and fuel pump inlet as high as 1.8°F (0.6°F higher than maximum observed on any engine during flight AS-501).

4.2.1 Fuel Pump Inlet Pressure Oscillations

The fuel pump inlet pressure experienced abnormal oscillations on firings with reduced NPSH as compared with firing 29A which had approximately 600 ft NPSH (Fig. 24). Firing 29A experienced fuel pump

inlet pressure oscillations with amplitudes of 0.5 psia at a frequency of 3 Hz. Firing 29B, which was typical of all firings with reduced NPSH, exhibited oscillations with amplitudes of 2.5 psia at 4 Hz (Fig. 29).

4.2.2 Fuel Pump Head Rise and Flow Coefficients

Head rise and flow coefficients used in this section are defined by the following relationships:

$$\text{Head rise coefficient } \psi = 32,150 \frac{H}{N^2}$$

where H = Total pump head rise, ft

N = Pump speed, rpm

$$\text{Flow coefficient } \phi = 0.2291 \frac{Q}{N}$$

where Q = Volumetric flow rate, gpm

N = Pump speed, rpm

Derivation of these equations is shown in Appendix V.

Flow coefficient relates tip speed of the inducer to the absolute fluid velocity and is proportional to the fluid velocity relative to the rotating surfaces. Head rise coefficient relates pump developed head and pump speed and is proportional to the energy imparted to the fluid by the pump. These coefficients define a unique operating characteristic of a pump under noncavitating, steady-state conditions.

Fuel pump head rise coefficient is presented as a function of thrust chamber temperature and NPSH in Fig. 135a. These data were reduced at t_0 + 0.58 sec to alleviate the effect of the main oxidizer valve opening. These data indicate that an approximate 35-percent increase in head rise coefficient was experienced as NPSH was reduced by approximately 600 ft and with thrust chamber temperatures ranging from -300 to -175°F. Since only one firing of this series was conducted with high NPSH, it was necessary to supplement this figure with data from previous test periods (J4-1801-21 through 23) utilizing the 230,000-lb_f-thrust configured engine. Test data were not available for comparison with thrust chamber temperatures warmer than -175°F and at the higher NPSH values in the aforementioned test series.

A similar comparison for fuel pump flow coefficient is presented in Fig. 135b. These data show a 10-percent decrease in flow coefficient was experienced with the reduced NPSH and over the same temperature range.

4.2.3 Gas Generator Outlet Initial Transient Temperature Peaks

The effect of reduced NPSH on gas generator outlet initial transient temperature peaks is shown in Fig. 136 for a specific set of starting conditions (-300°F thrust chamber temperature and high starting energy). Sufficient data were not available to generate a family of these curves for various starting conditions. These data show that a significant increase in gas generator outlet temperature occurred as NPSH was reduced from 180 to 80 ft at engine start. Firing 29D was prematurely terminated by the engine safety cutoff system because of the excessive gas generator outlet temperature peak of 2460°F. The gas generator control valve was inadvertently chilled on this firing (Table VI). This resulted in delayed gas generator control valve poppet movement (Table VII) and delayed gas generator ignition (40 msec). Sufficient data are not available at this time to determine the effect of this valve temperature on gas generator outlet transient temperatures.

4.3 START TRANSIENT INVESTIGATION OF THE EFFECTS OF THRUST CHAMBER TEMPERATURE

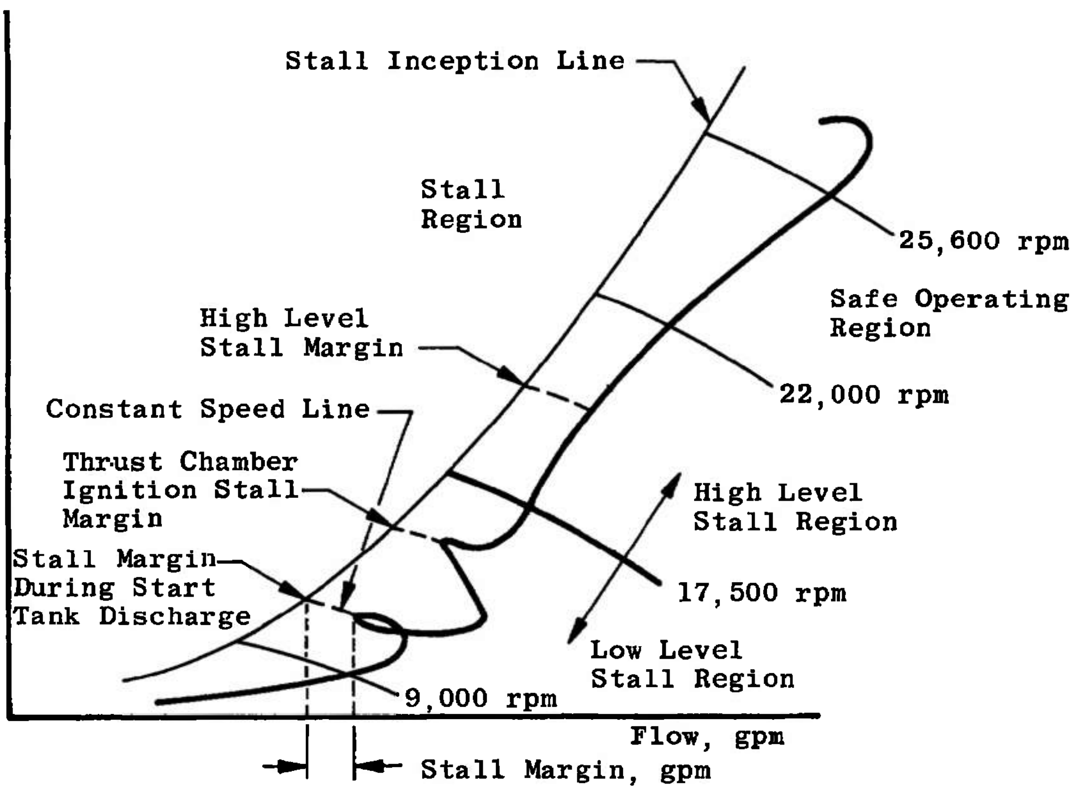
During AS-500 flight series prelaunch activities, the S-II stage J-2 rocket engine thrust chambers are conditioned to obtain temperature in the range of from -200 to -275°F at liftoff (Ref. 6). Since certain S-1C/S-II interstage components must be maintained at a temperature warmer than approximately -100°F, any recycle in the countdown, occurring after the thrust chambers have been conditioned, imposes a hold to allow the interstage area to return to ambient temperature. If this hold were not imposed, rechilling of the thrust chambers would cause these interstage component temperatures to decrease below the minimum.

If the S-II stage engine thrust chambers could be conditioned to temperatures in the range of approximately -100°F, then holds initiated during the conditioning period could be tolerated and holds incurred as a result of recycles would be eliminated. Based on AS-501 flight data, thrust chamber temperatures at engine start would be approximately -60°F. Therefore, testing in the later part of this test series was directed toward these warmer thrust chamber temperatures utilizing the lower than minimum engine model specification fuel pump NPSH. The resulting effect on fuel pump operation during start tank discharge is presented in the following sections.

4.3.1 Fuel Pump Stall Margin

Fuel pump stall margin before thrust chamber ignition was affected primarily by thrust chamber temperature in a given range of fuel pump

NPSH. This effect is shown in Fig. 137. The warmer thrust chamber, having the higher fuel flow resistance, reduced stall margin, whereas thrust chamber temperatures of approximately -300°F had essentially no resistance to fuel flow and therefore, produced the highest stall margin. Stall margins were read along a constant speed line between the stall inception line and the closest approach of the actual head/flow data in the region of interest as shown below.



Three partial transition firings (J4-1801-31C, D, and E) were conducted to determine the thrust chamber temperature at which the fuel pump will stall. For these firings, engine cutoff was programmed to occur at t_0 + 0.600 sec.to avoid possible excessive gas generator outlet temperature peaks and resulting turbine damage. Average throat-to-exit thrust chamber temperatures for the three firings were +46, +7, and -64°F. During firings 31C and 31D, the fuel pump stalled and exhibited no tendency to recover before engine cutoff. During firing 31E fuel pump head/flow data entered low level stall region by approximately 150 gpm. Flow had not increased significantly before engine cutoff signal but did increase approximately 1000 gpm before the main fuel valve started to close. Flow coefficient ϕ' (based on fuel pump discharge conditions) where

$$\phi' = \frac{\omega}{ArN}$$

ω = Mass flow

= Fluid density

A = Pump discharge area

r = Impeller radius

N = Pump speed

is shown in Fig. 138. It will be noted that at the time of initial main fuel valve closure, flow coefficient on firing 31E is above 0.23, which is the point at which Rocketdyne-supplied steady-state test data show the March 15 turbopump to be in a condition of stall. Since gas generator ignition did not occur on this firing (31E), no conclusion could be drawn concerning the success of a main-stage firing with these thrust chamber temperatures.

On the basis of pump performance exhibited during firings 31C, D, and E, thrust chamber temperatures of approximately -110°F at engine start were utilized during test periods J4-1801-32 and 33. All firings during these test periods were successfully accomplished with stall margins during start tank discharge ranging from 400 to 750 gpm as start tank pressure at engine start was increased from 1200 to 1400 psia utilizing fuel pump NPSH of approximately 125 ft at engine start. No engine component damage was incurred as a result of these firings.

4.3.2 Fuel Pump Head Rise and Flow Coefficients

Thrust chamber temperature effect on fuel pump flow coefficient (ϕ) and head coefficient (ψ) as defined in Section 4.2.3 is shown in Fig. 135. Flow coefficient shows a tendency to decrease as thrust chamber temperature at engine start becomes warmer. In other words, for a given pump speed, fluid velocity tends to decrease for the warmer thrust chamber temperature. Thus, the impeller blades are operating at a higher angle of attack and, therefore, closer to a condition of stall.

Head rise coefficient shows a tendency to increase as thrust chamber temperature at engine start increases. This is because of the higher back pressure produced by the higher fuel flow resistance.

4.4 POST-TEST INSPECTION

4.4.1 Test J4-1801-28

Post-test inspection of the engine and fuel low pressure duct showed each to be in satisfactory condition. However, the battleship stage oxidizer sump seal failed and caused excessive fires in the engine/stage area resulting in damage to seven instrumentation cables. The seal and damaged cables were subsequently replaced.

4.4.2 Test J4-1801-29

Post-test inspection showed the engine and fuel inlet duct to be in satisfactory condition. Because of the excessive gas generator outlet temperature during firing 29D, the fuel turbine blades were inspected for erosion. No significant erosion was noted. The gas generator temperature probe was not damaged, but a redundant probe was installed.

4.4.3 Test J4-1801-30

During firing 30A, the main fuel valve exhibited abnormal delay and opening times. Immediately after the firing, the thrust chamber experienced an abnormal chilldown when propellants were permitted into the engine. Post-test inspection of the main fuel valve, installed before this test period, showed the valve gate to be partially open. Otherwise, the engine was in satisfactory condition.

4.4.4 Test J4-1801-31

Post-test inspection showed the engine to be in satisfactory condition, except for the gas generator control valve. The fuel poppet was found to be leaking, which was observed in the control room after firing 31B. Hence, the valve was replaced.

4.4.5 Test J4-1801-32

Post-test inspection showed the engine to be in satisfactory condition. No hardware damage was noted.

4.4.6 Test J4-1801-33

Post-test inspection showed the engine to be in satisfactory condition. No hardware damage was noted.

SECTION V
SUMMARY OF RESULTS

The results of the 24 firings and two fuel lead tests of the Rocketdyne J-2 rocket engine conducted between February 15, 1968, and March 20, 1968, in Test Cell J-4 are summarized as follows:

1. S-II stage center engine low pressure fuel duct fluid dynamic characteristics (with the exception of flight-imposed acceleration) were successfully simulated utilizing a specially configured duct during this test series. Heat added to this duct produced differential temperatures between the fuel tank bulk and fuel pump inlet as high as 1.8°F (0.6°F higher than maximum observed on any engine during flight AS-501).

2. Firings of this test series were successfully accomplished with NPSH as low as 70 ft at engine start (80 ft below minimum model specifications). These conditions were obtained by reducing fuel pump inlet pressure to approximately 26.0 psia (2 psi lower than minimum model specifications and 1 psi lower than minimum expected on flights AS-502, AS-503, and AS-504).

   Testing with this reduced NPSH was observed to have the following effects on the fuel pump and engine start transient operation:

   a. A significant increase in gas generator outlet initial transient temperature peaks (for firings with low resistance to fuel flow, -300°F thrust chamber, and high starting energy).

   b. Fuel pump head rise coefficient was observed to increase, and fuel pump flow coefficient was observed to decrease.

   c. Fuel pump inlet pressure oscillations with five times the amplitude and 33 percent higher frequency were observed as compared with firing 29A, which had 60 percent of maximum engine model specification NPSH.

3. Firings of this test series were successfully accomplished with thrust chamber average temperatures of approximately -110°F at engine start. These increased temperatures were observed to have the following effects on the fuel pump start transient.

   a. Low level stall margins ranging from 400 to 750 gpm were observed as start tank pressure at engine start was increased from 1200 to 1400 psia.

b. Fuel pump head coefficient was observed to increase, and flow coefficient was observed to decrease with respect to colder thrust chamber temperatures.

4. Fuel pump stall was observed to occur at thrust chamber temperatures at engine start of +46 and +7°F. Data on fuel pump operation conducted with a thrust chamber of -64°F were inconclusive but appeared to be marginal.

REFERENCES

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APPENDIXES

I. ILLUSTRATIONS
II. TABLES
III. INSTRUMENTATION
IV. METHODS OF CALCULATION (PERFORMANCE PROGRAM)
V. METHODS OF CALCULATION (HEAD RISE AND FLOW COEFFICIENTS)

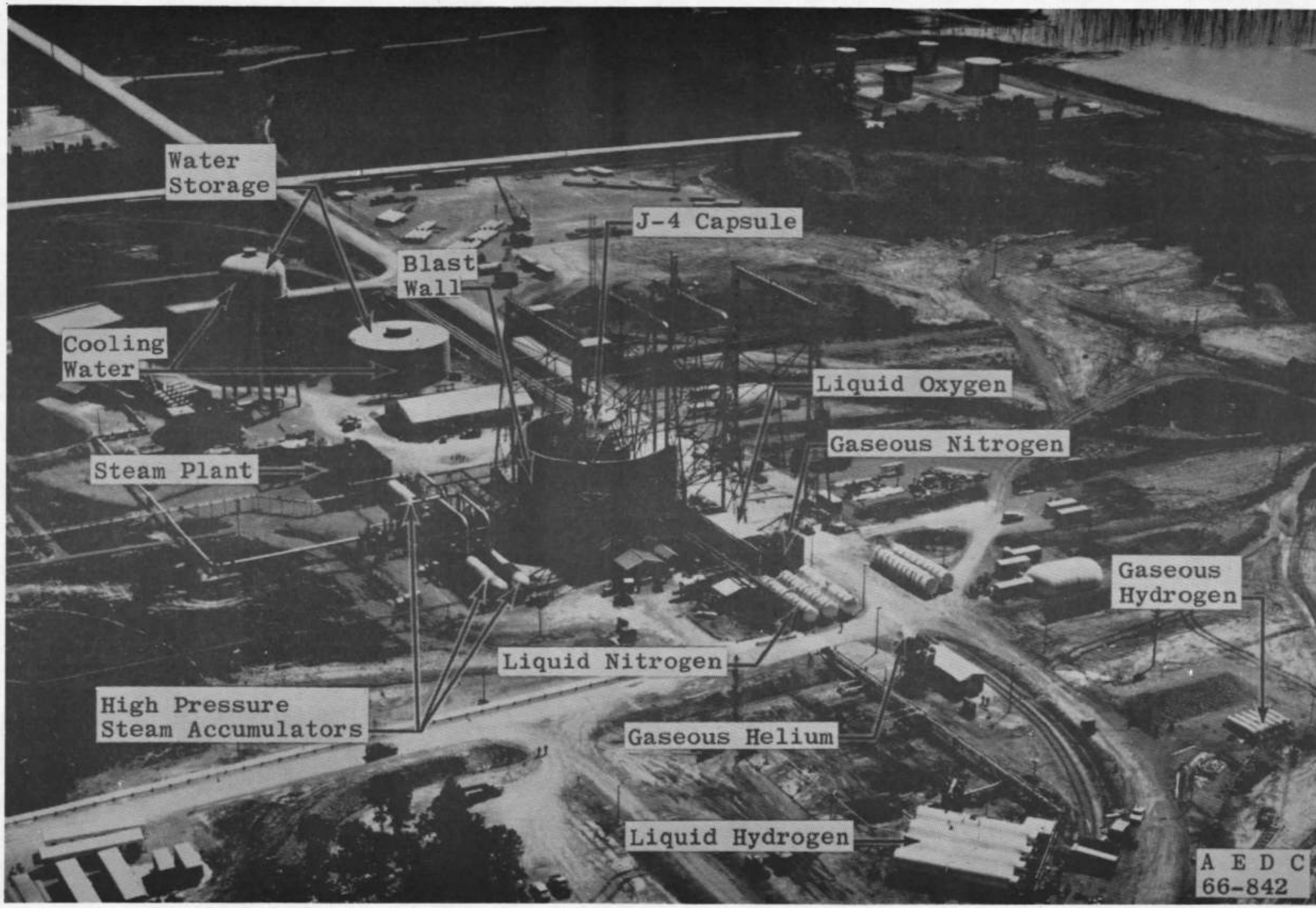


Fig. 1 Test Cell J-4 Complex

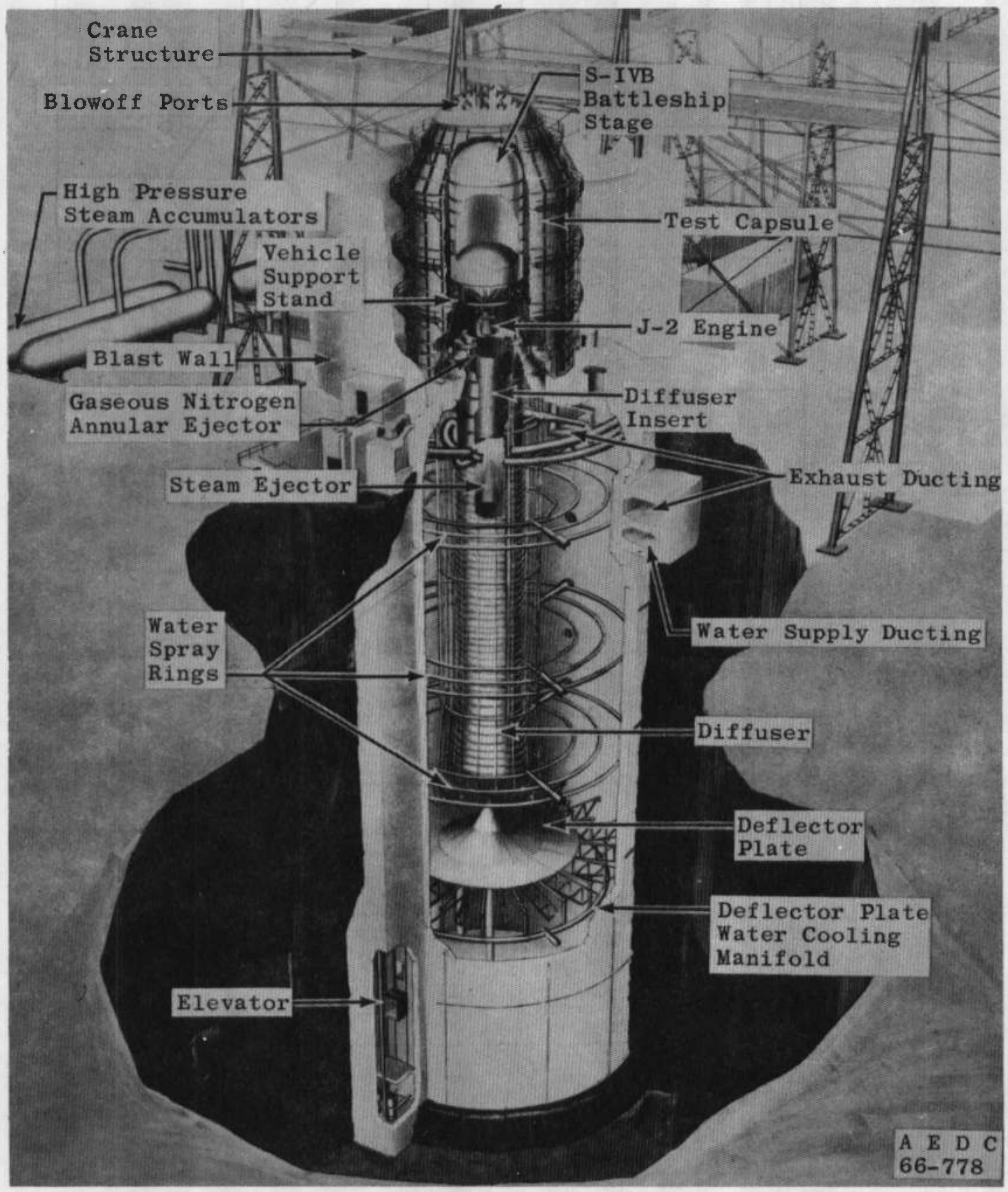


Fig. 2 Test Cell J-4, Artist's Conception

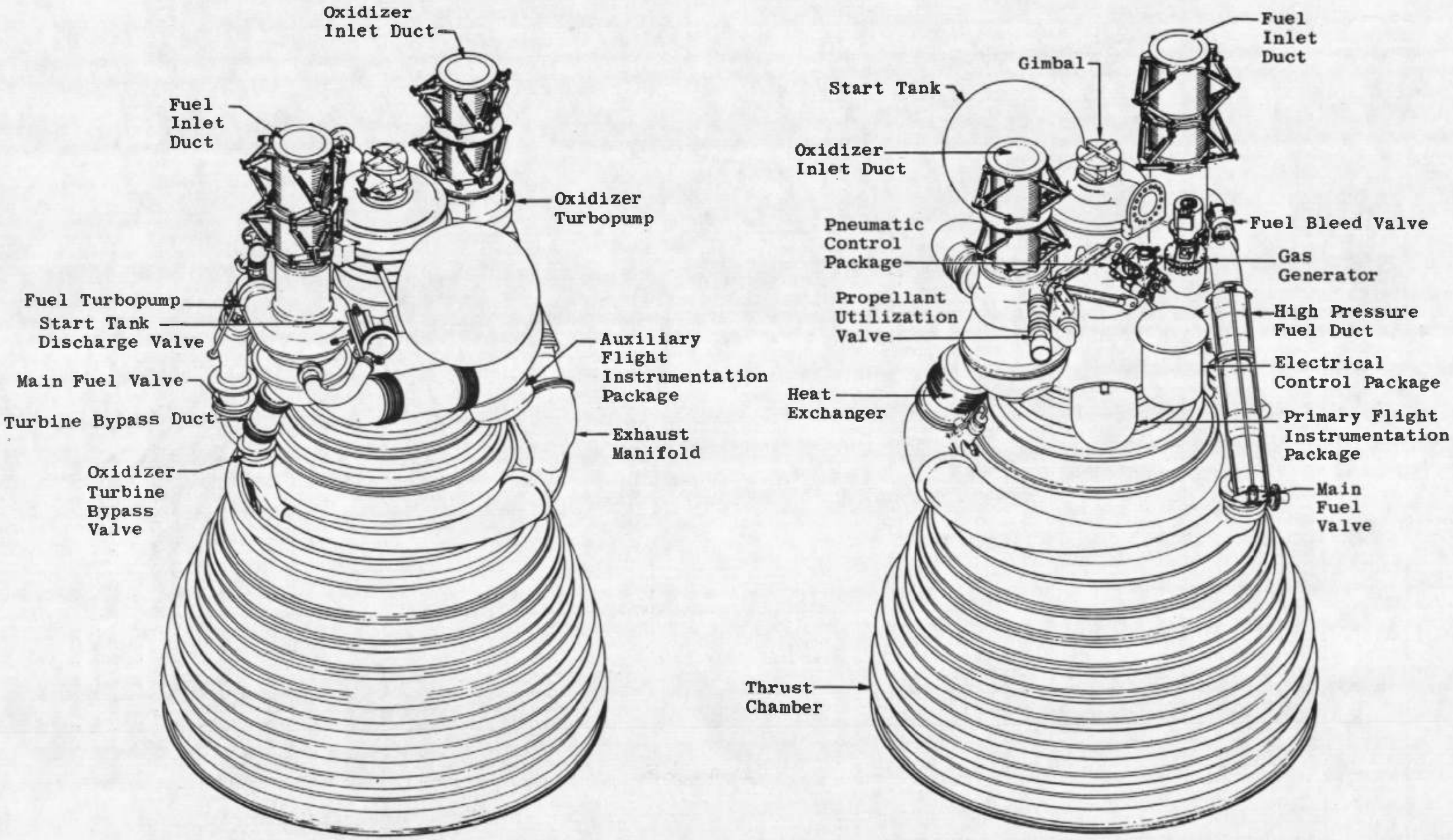
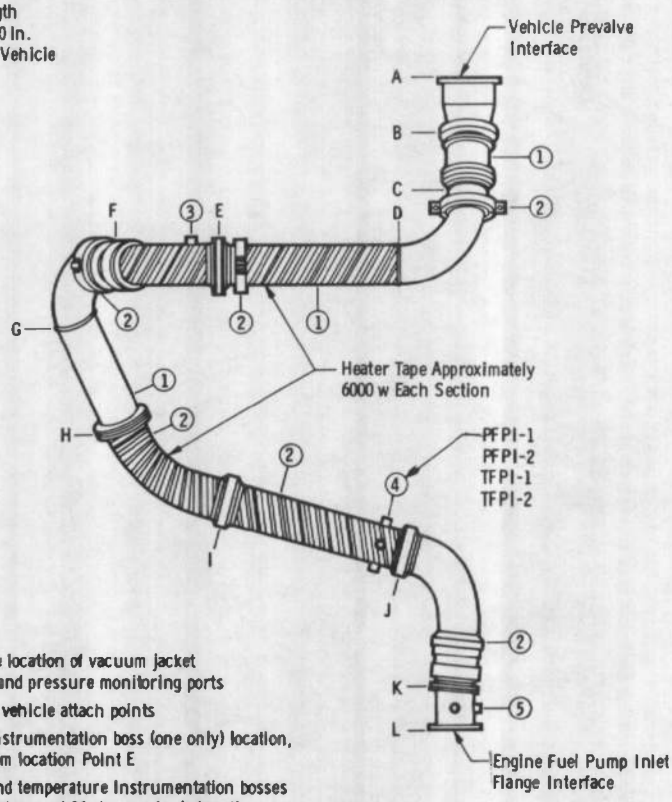


Fig. 3 Engine Details

SII Fuel Ouct Configuration for AEDC Test

Location Point	Approximate Length, In.	Approximate Minimum 10, In.	Type of Insulation: Vac. Jacket	Type of Insulation: Laro-dyne	Type of Joint: Upper	Type of Joint: Lower
A to B	13.72	7.944		X	Marmon Flange	Bolted Flange
B to C	11.00	7.950	X		Bolted Flange	Bellows
C to D	29.63	7.900		X	Bellows	Welded
0 to E	41.14	7.950	X		Welded	Bellows
E to F	28.71	7.950	X		Bellows	Bolted Flange
F to G	26.63	7.900		X	Bolted Flange	Welded
G to H	29.13	7.950	X		Welded	Bolted Flange
H to I	44.88	7.950	X		Bolted Flange	Bellows
I to J	61.18	7.950	X		Bellows	Bellows
J to K	41.78	7.890	X		Bellows	Bolted Flange
K to L	9.50	8.280		X	Bolted Flange	Bolted Flange

Approximate Total Length
A through L - 337.30 In.
Approximate SII Total Vehicle
Length - 355.08 In.



① Approximate location of vacuum jacket evacuation and pressure monitoring ports

② Duct to test vehicle attach points

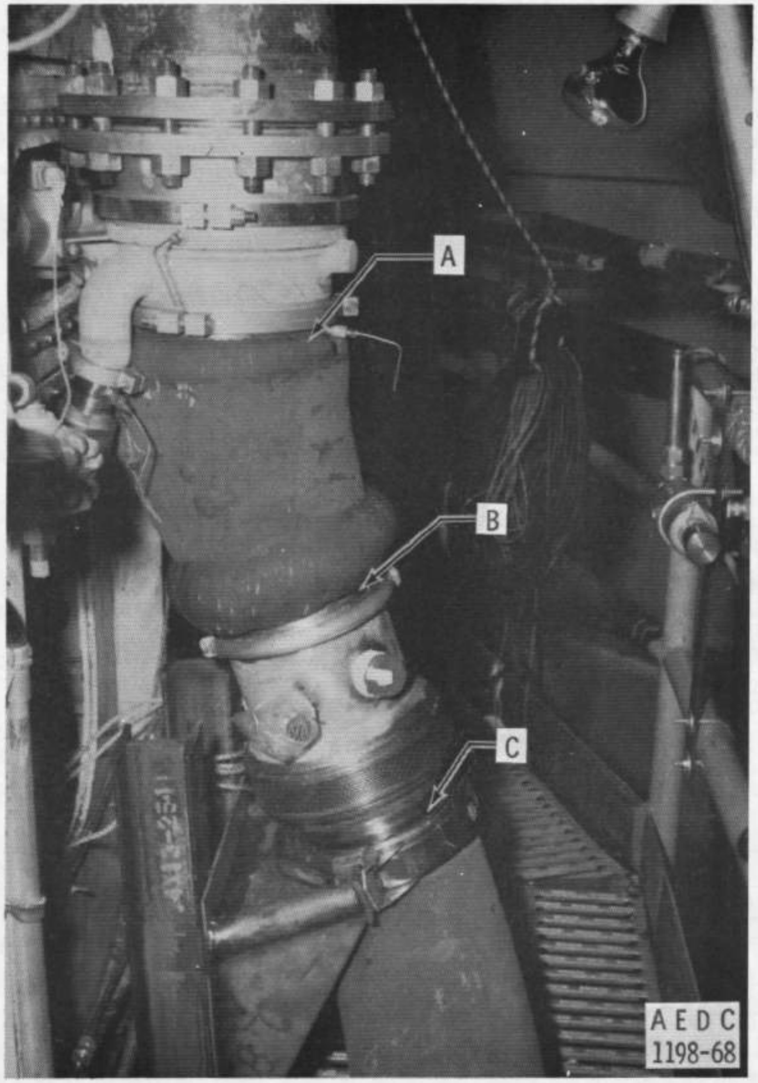
③ Pressure instrumentation boss (one only) location, 4.85 In. from location Point E

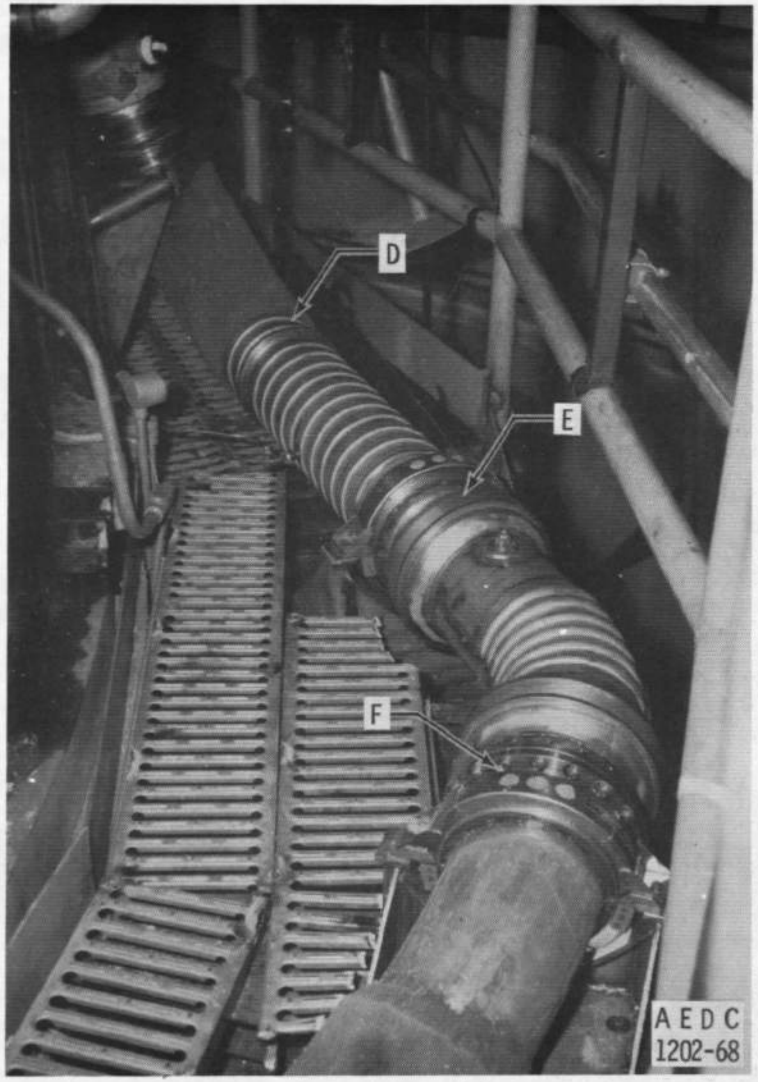
④ Pressure and temperature instrumentation bosses (2 pr. and 2 temp. at 90-deg spacing), Location, 4.50 In. from location Point J

⑤ Pressure and temperature instrumentation bosses (90-deg spacing with one temperature location between two pressure bosses), Location, 6.35 In. from location Point L

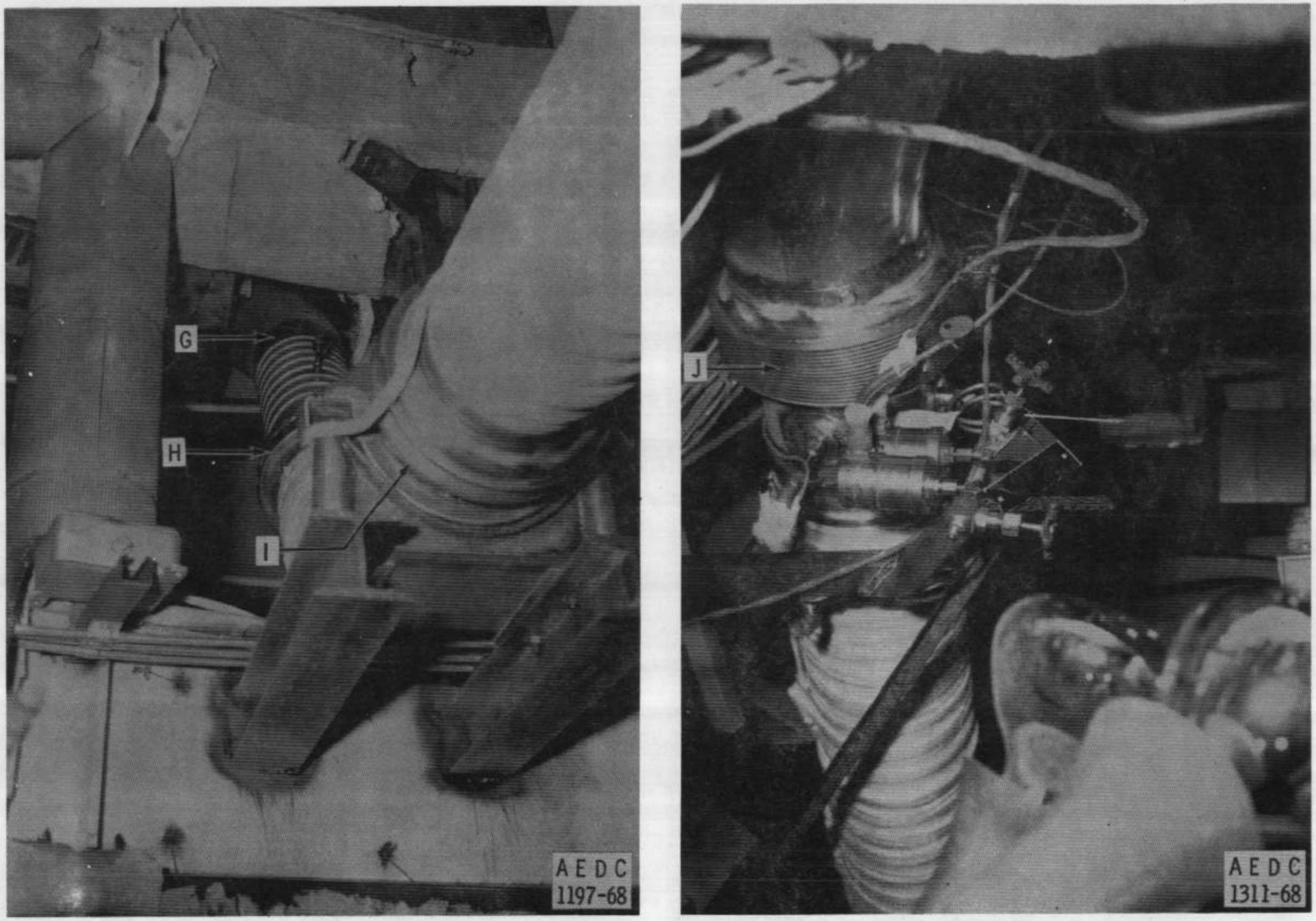
a. Schematic

Fig. 4 S-II Center Engine Configuration Fuel Low Pressure Duct



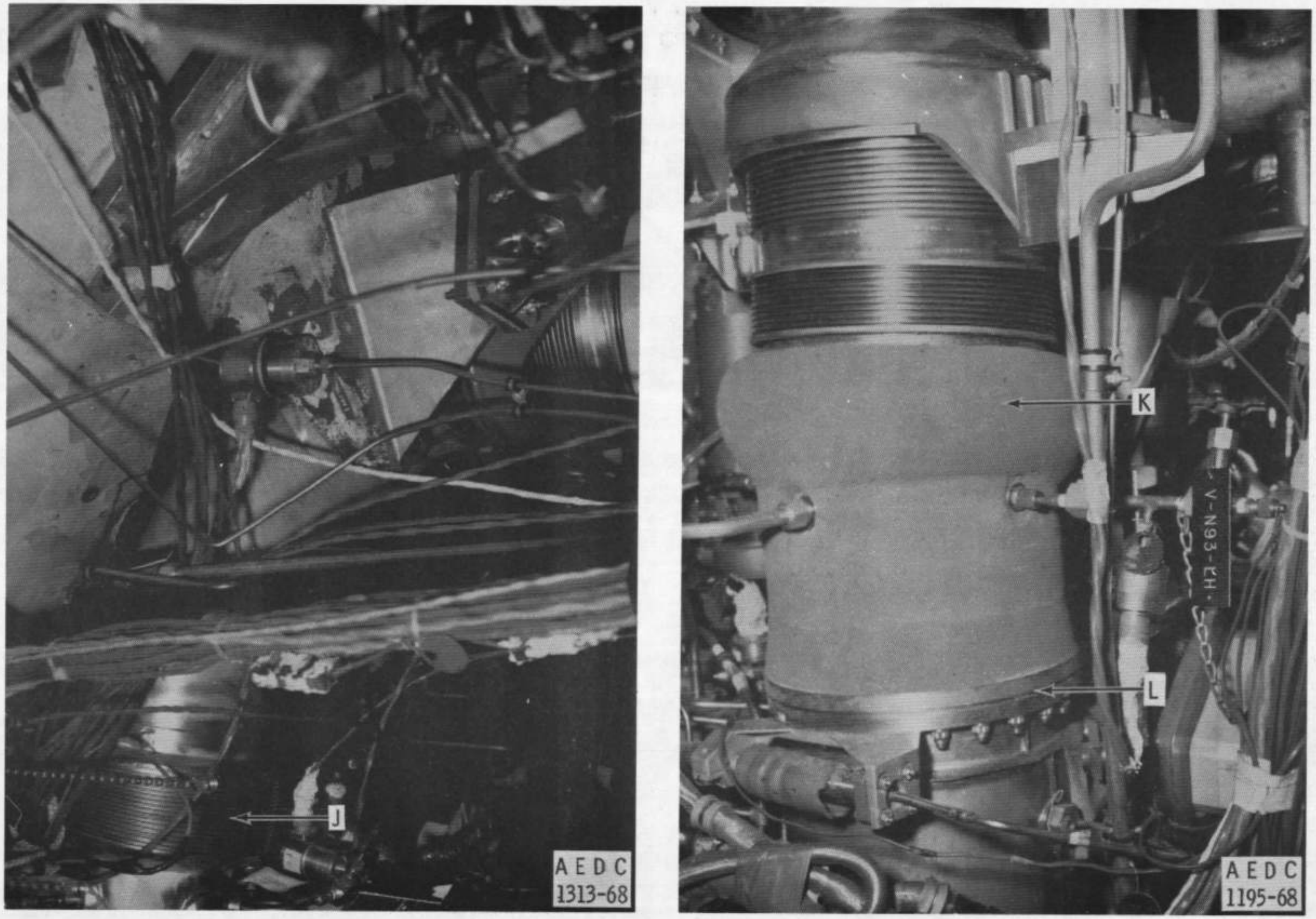


b. Photographs
Fig. 4 Continued



b. Continued

Fig. 4 Continued



b. Concluded

Fig. 4 Concluded

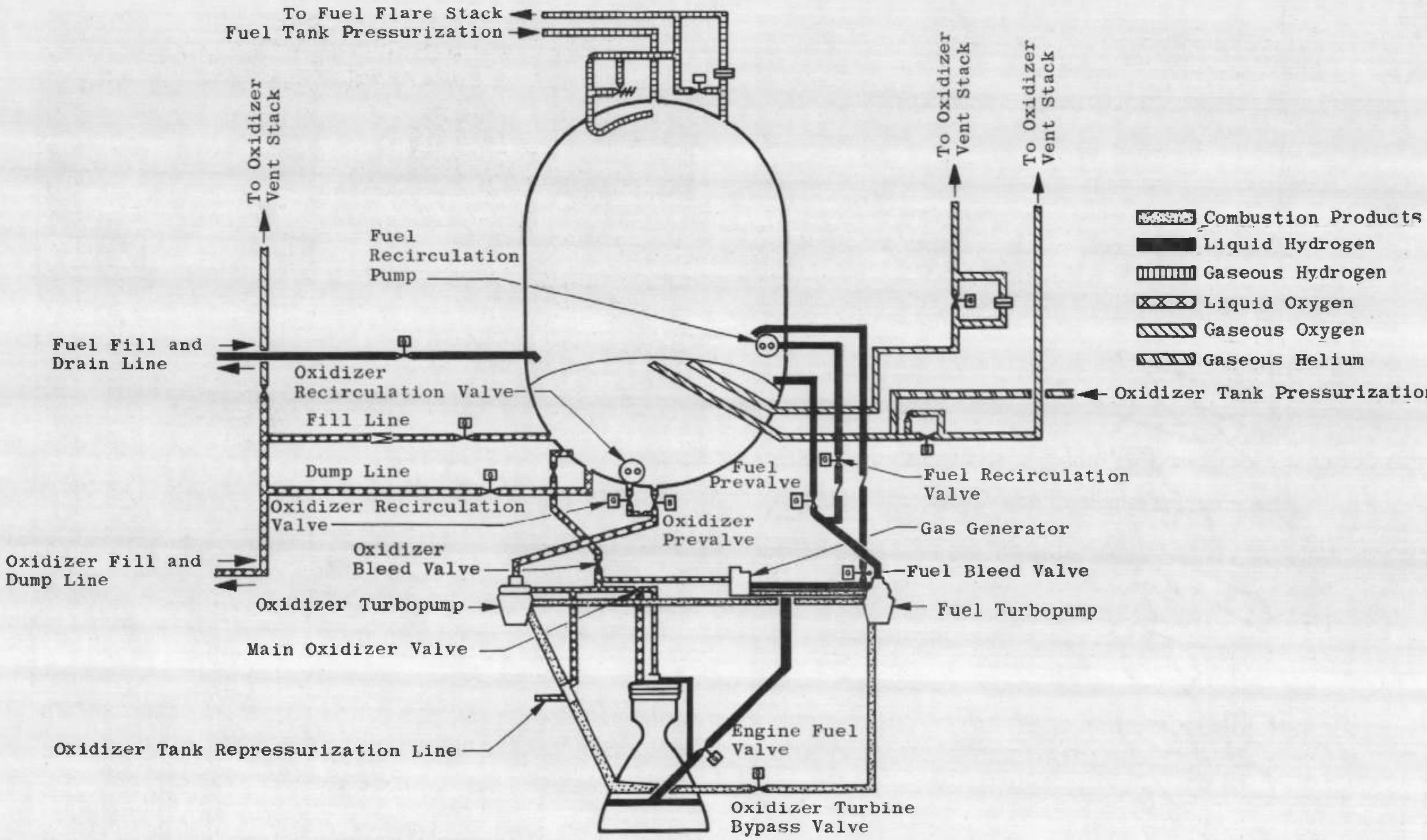


Fig. 5 S-IVB Battleship Stage/J-2 Engine Schematic

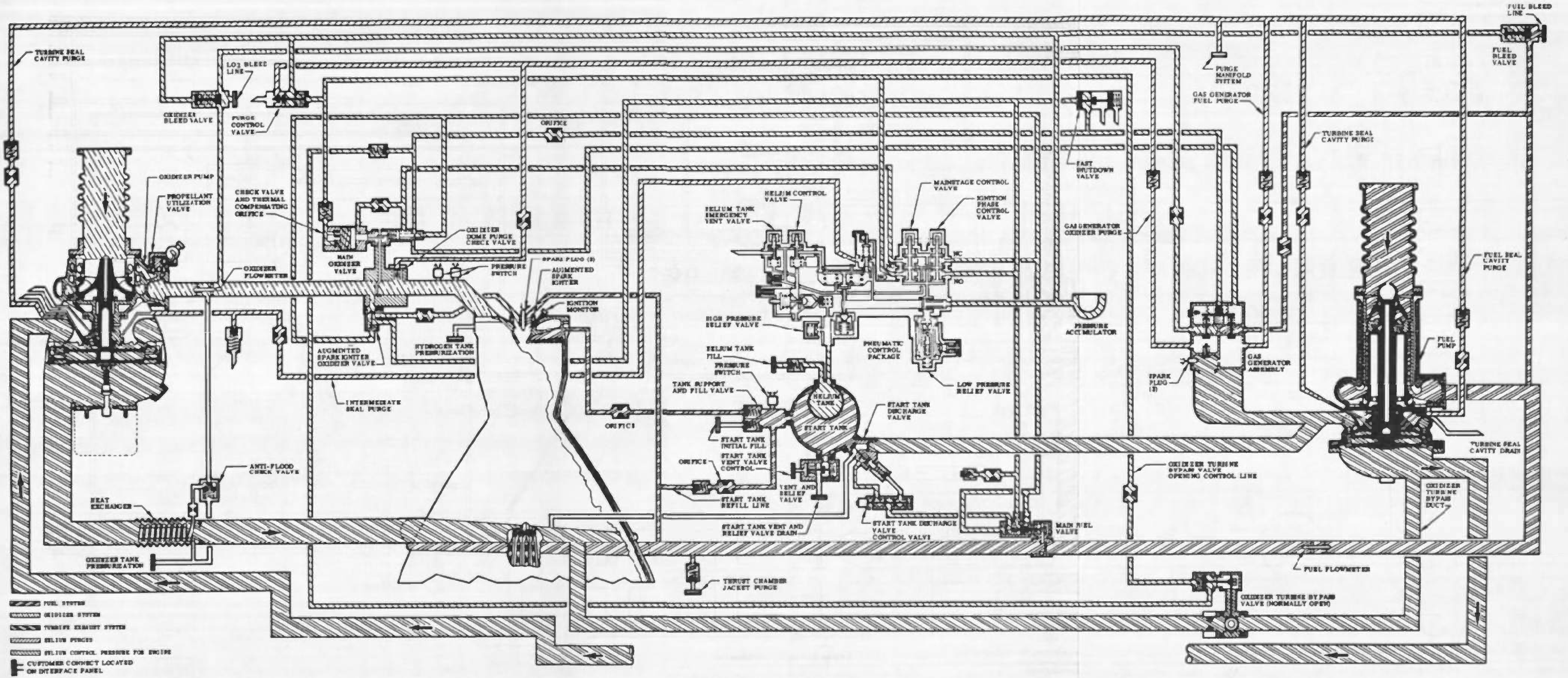


Fig. 6 Engine Schematic

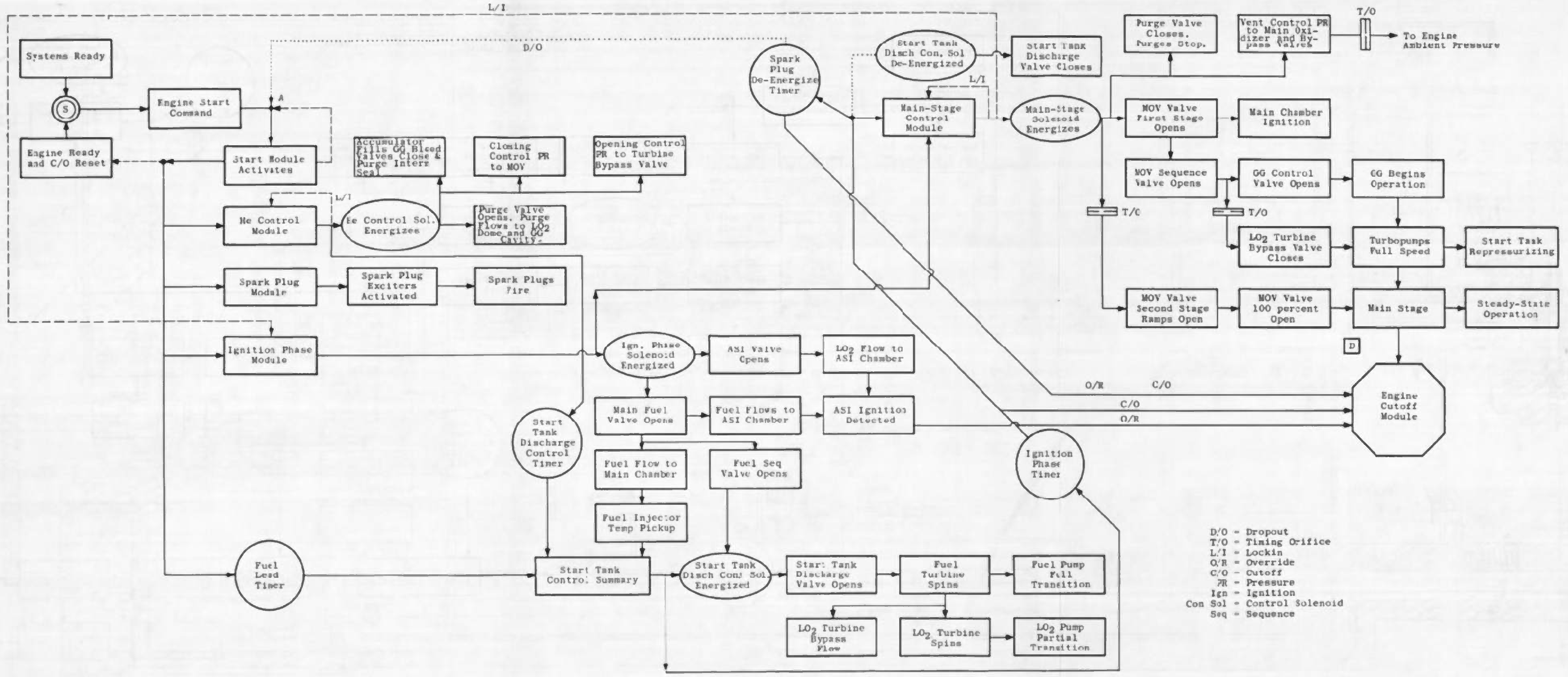
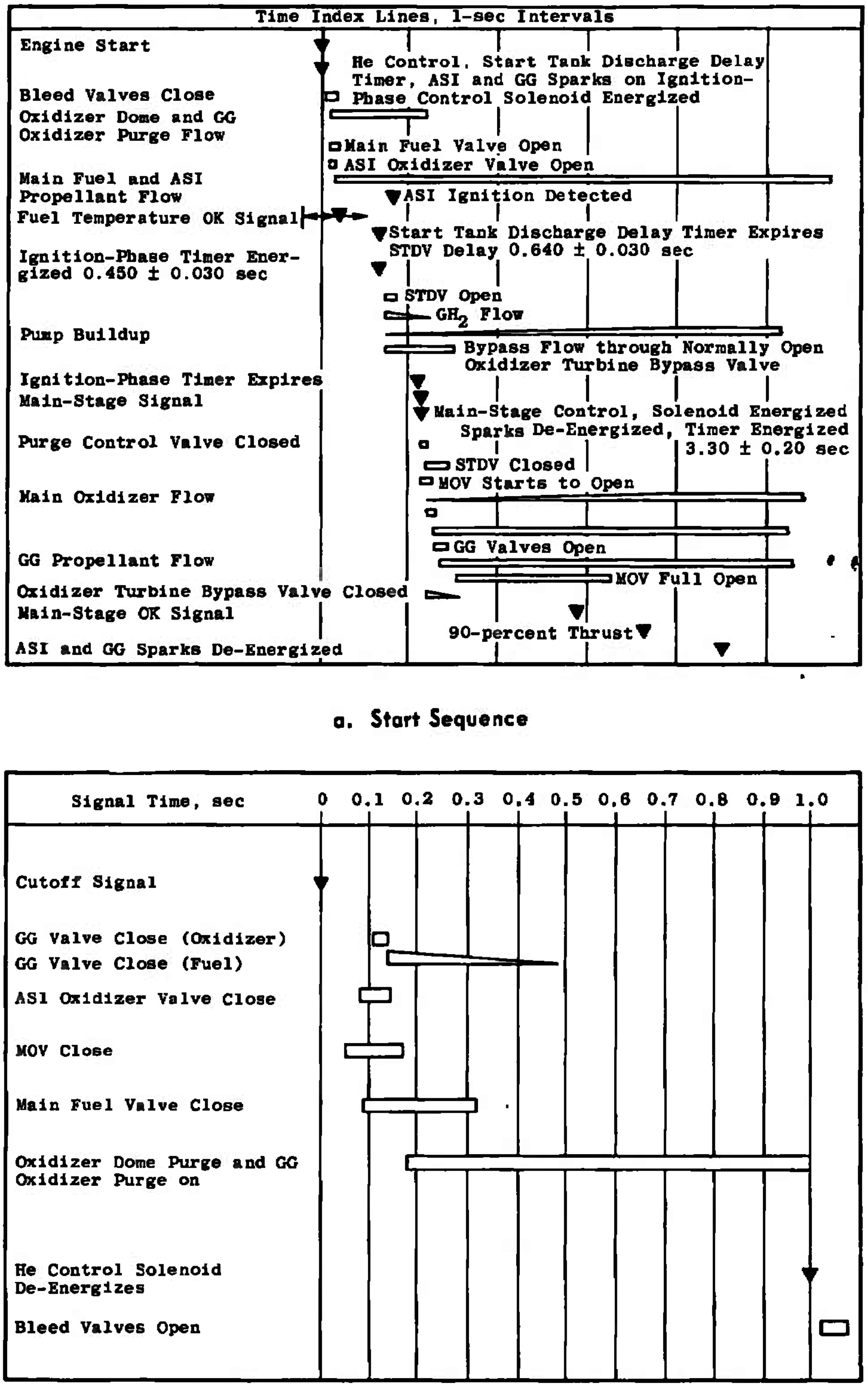


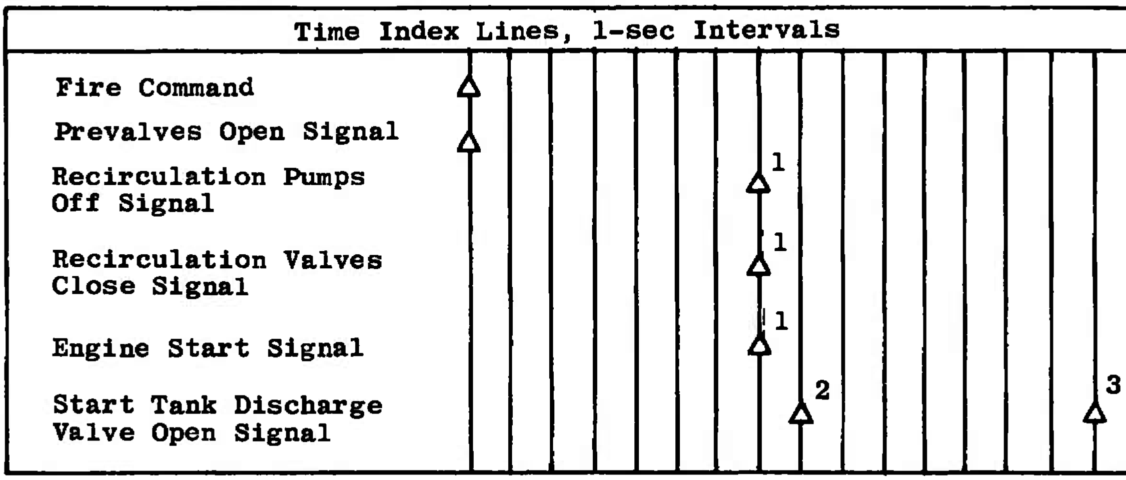
Fig. 7 Engine Start Logic Schematic



a. Start Sequence

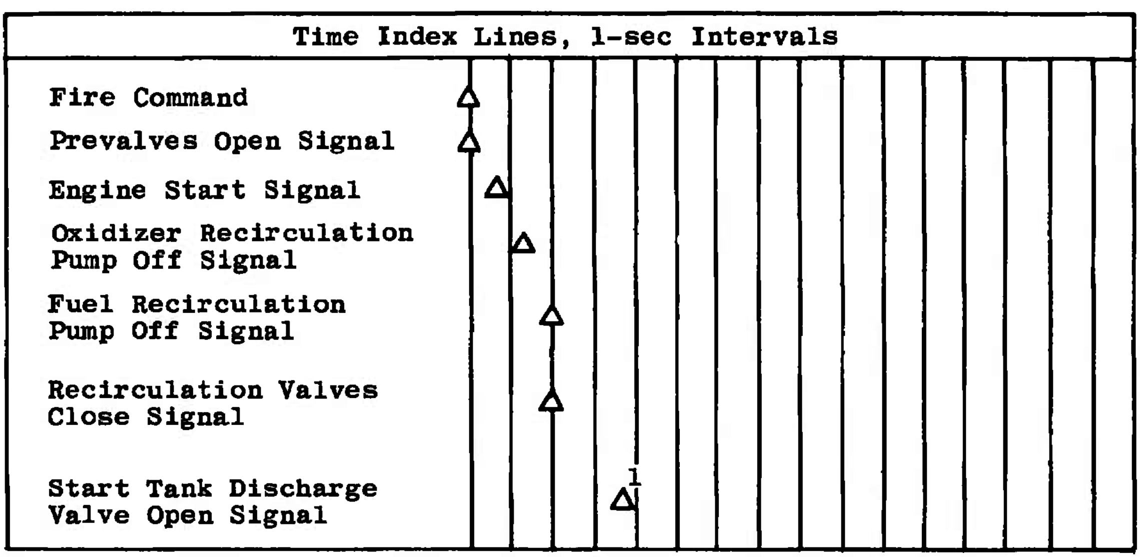
b. Shutdown Sequence

Fig. 8 Engine Start and Shutdown Sequence



[1]Nominal Occurrence Time (Function of Prevalves Opening Time)
[2]One-sec Fuel Lead (S-II/S-V and S-IVB/S-IB)
[3]Eight-sec Fuel Lead (S-IVB/S-V and S-IB Orbital Restart)

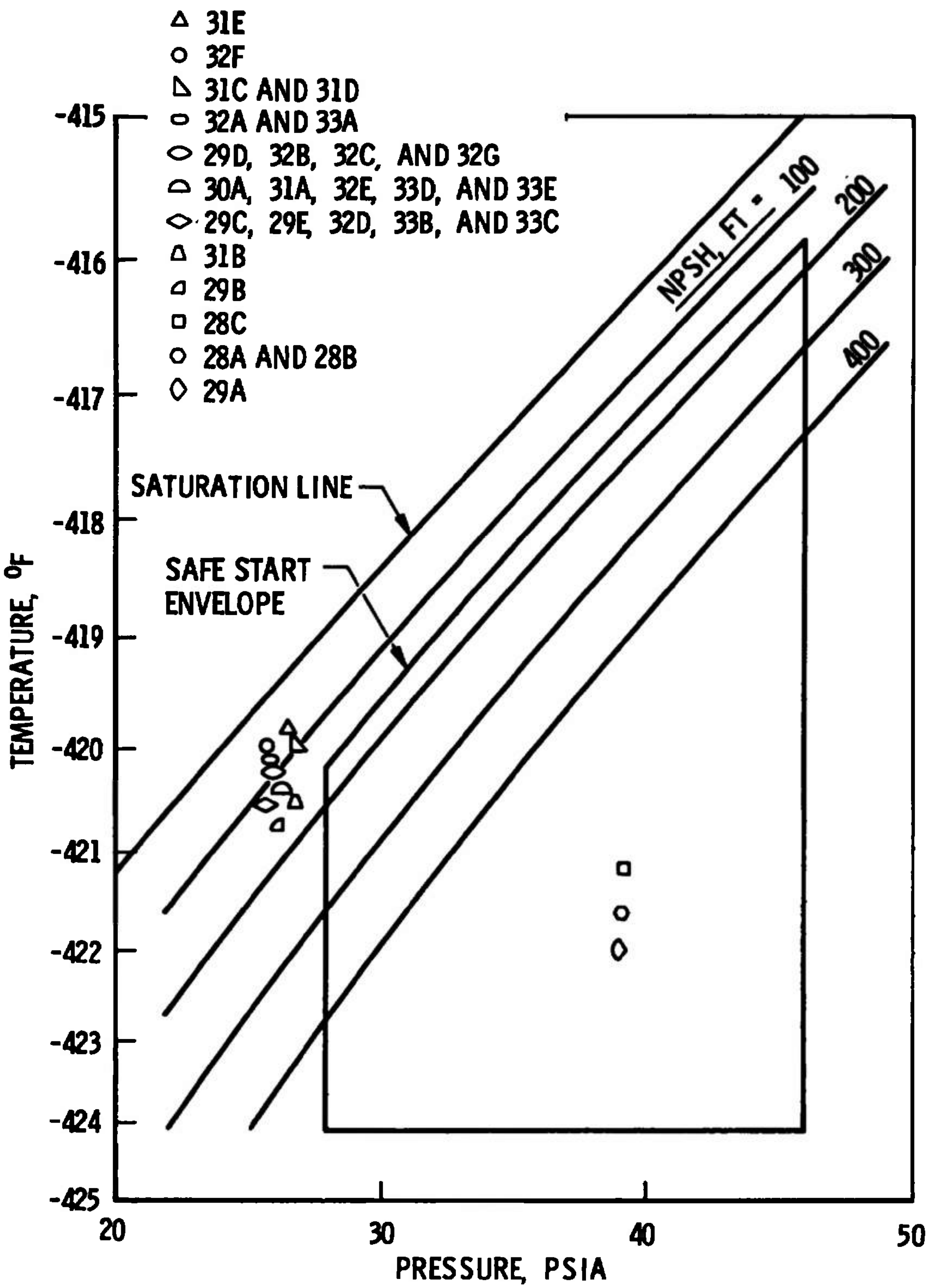
c. "Normal" Start Sequence



[1]Three-sec Fuel Lead (S-IVB/S-V First Burn)

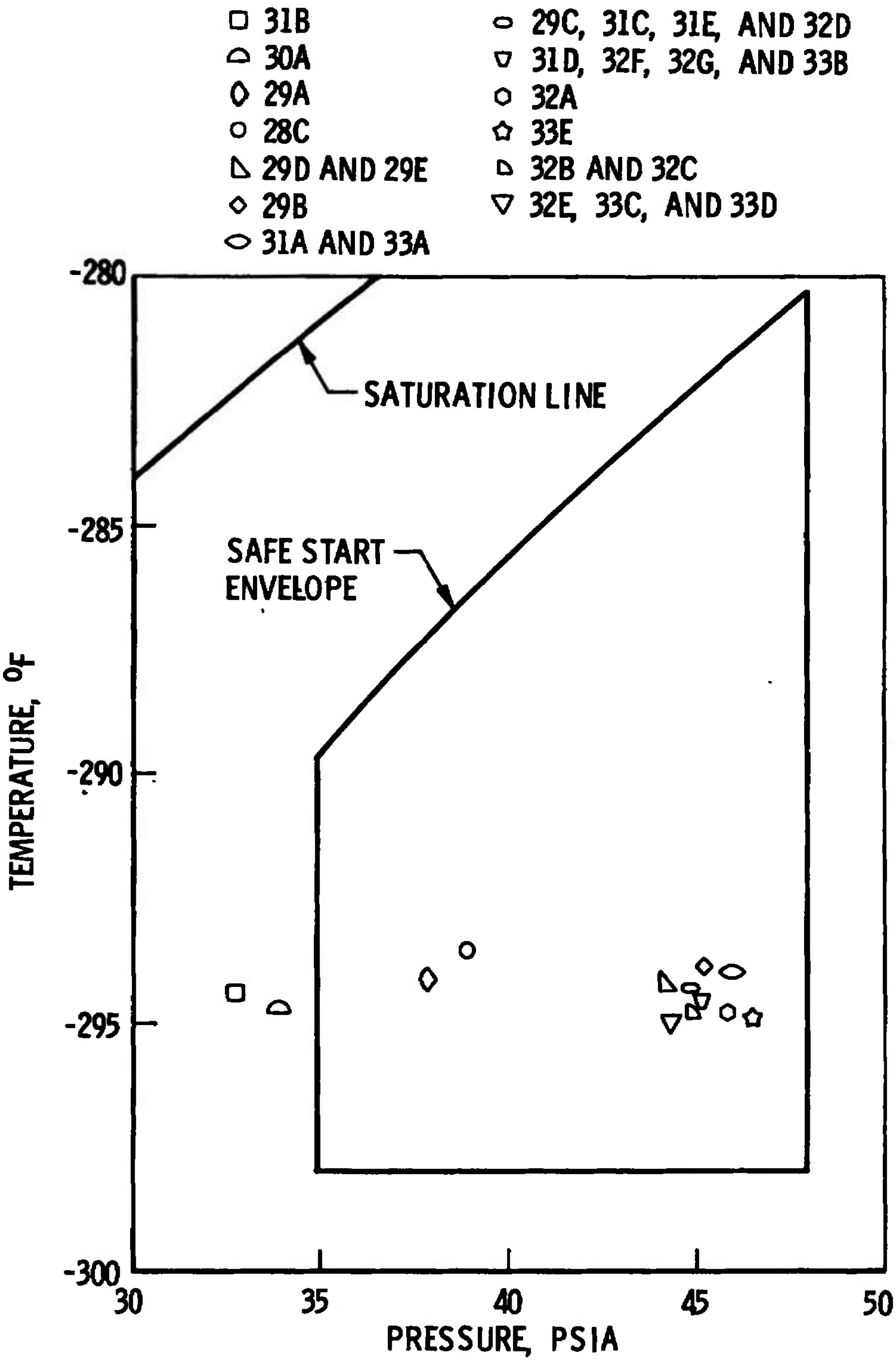
d. "Auxiliary" Start Sequence

Fig. 8 Concluded



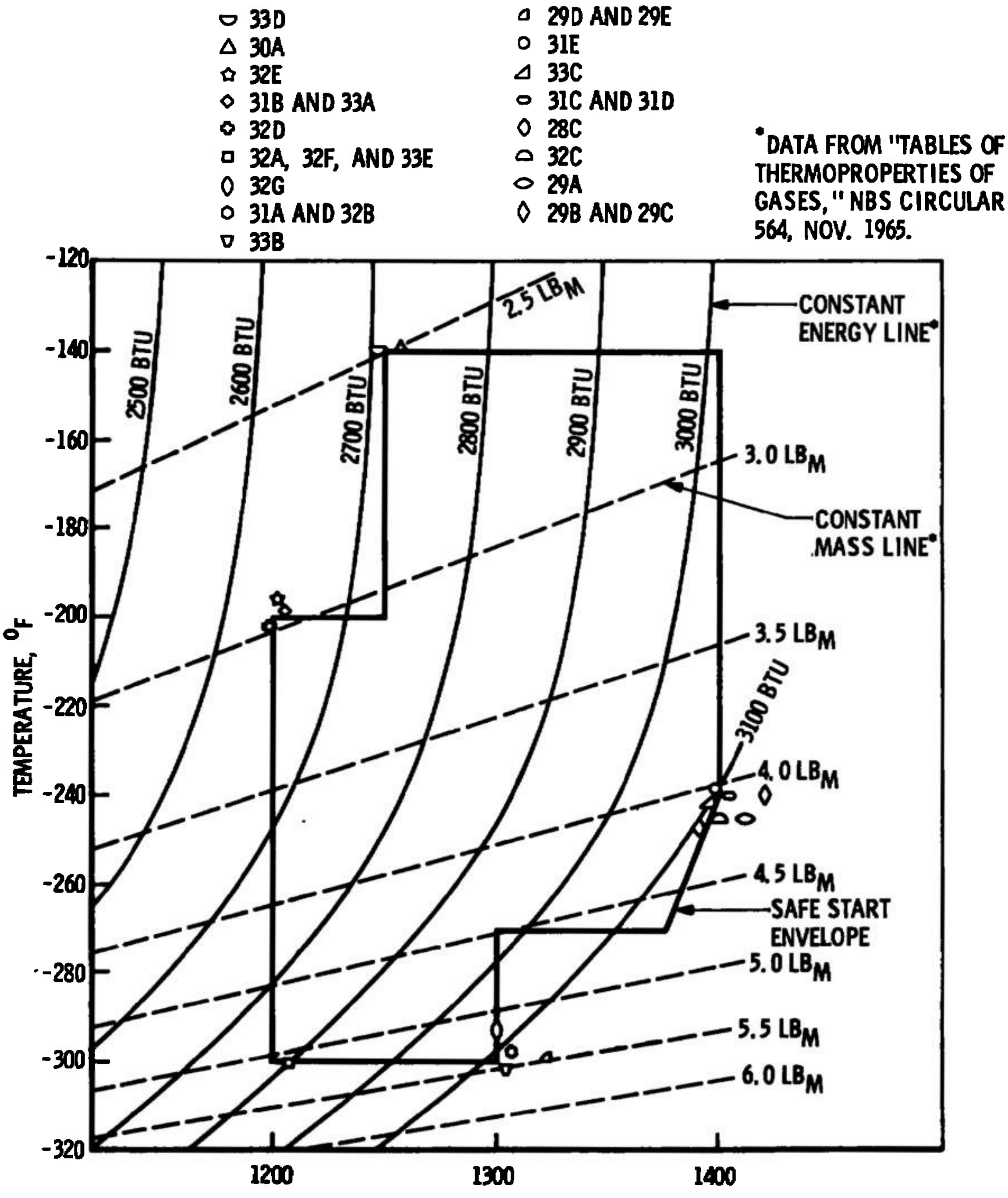
a. Fuel Pump Inlet Start Conditions

Fig. 9 Engine Start Conditions for Pump Inlets and the Start Tank



b. Oxidizer Pump Inlet Start Conditions

Fig. 9 Continued



c. Start Tank Starting Conditions
Fig. 9 Concluded

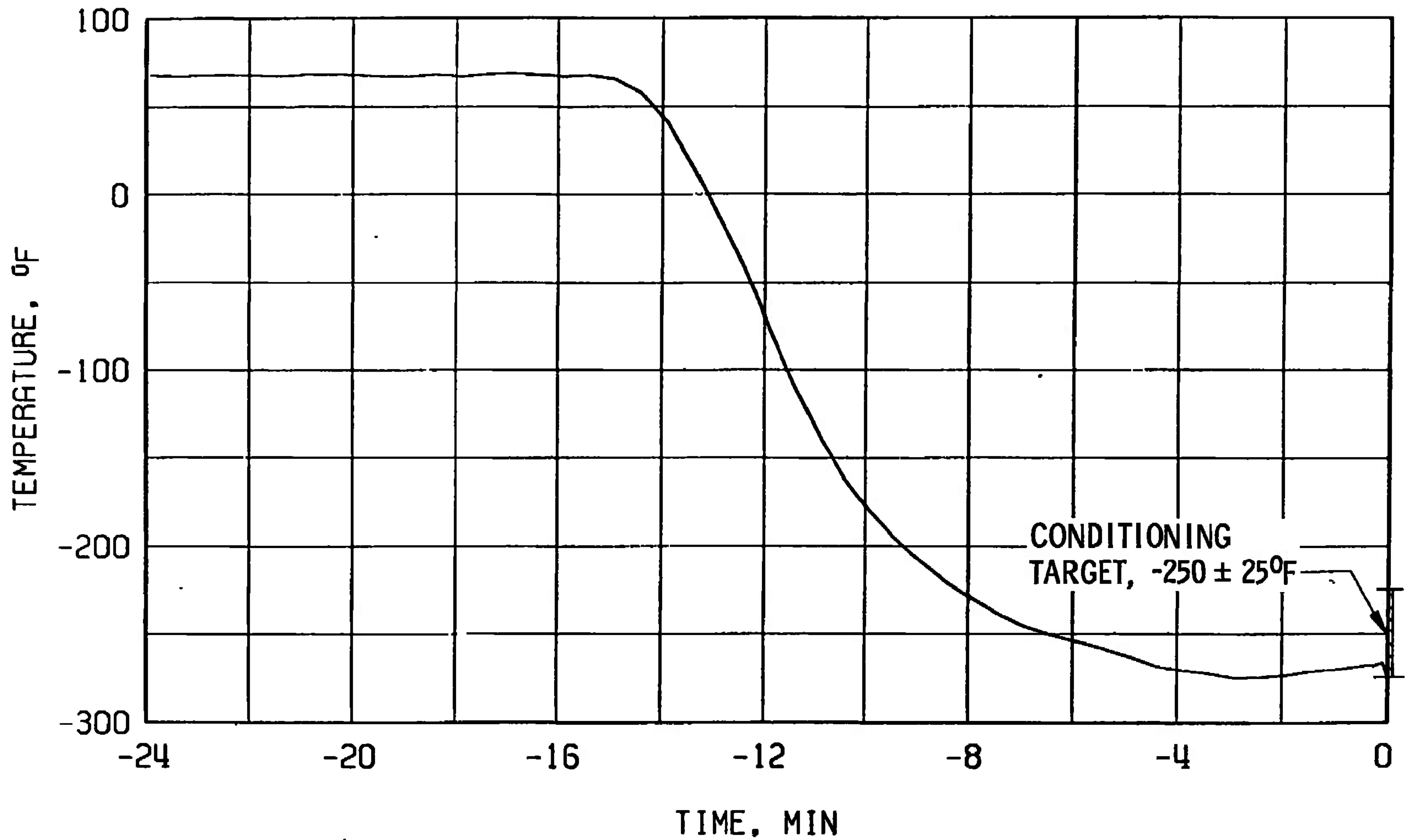


Fig. 10 Thrust Chamber Thermal Conditioning History, Test 28A

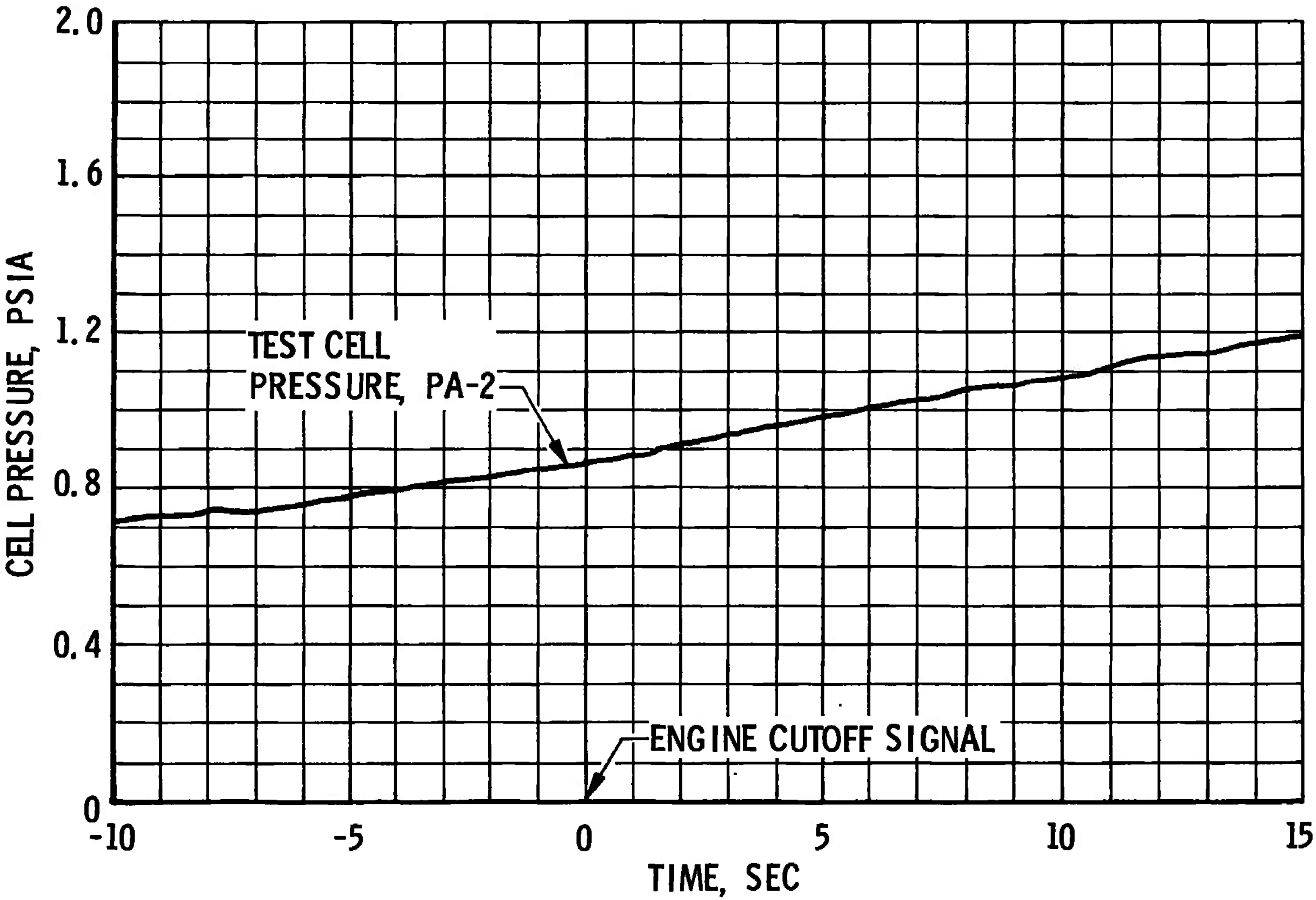


Fig. 11 Engine Ambient Pressure, Test 28A

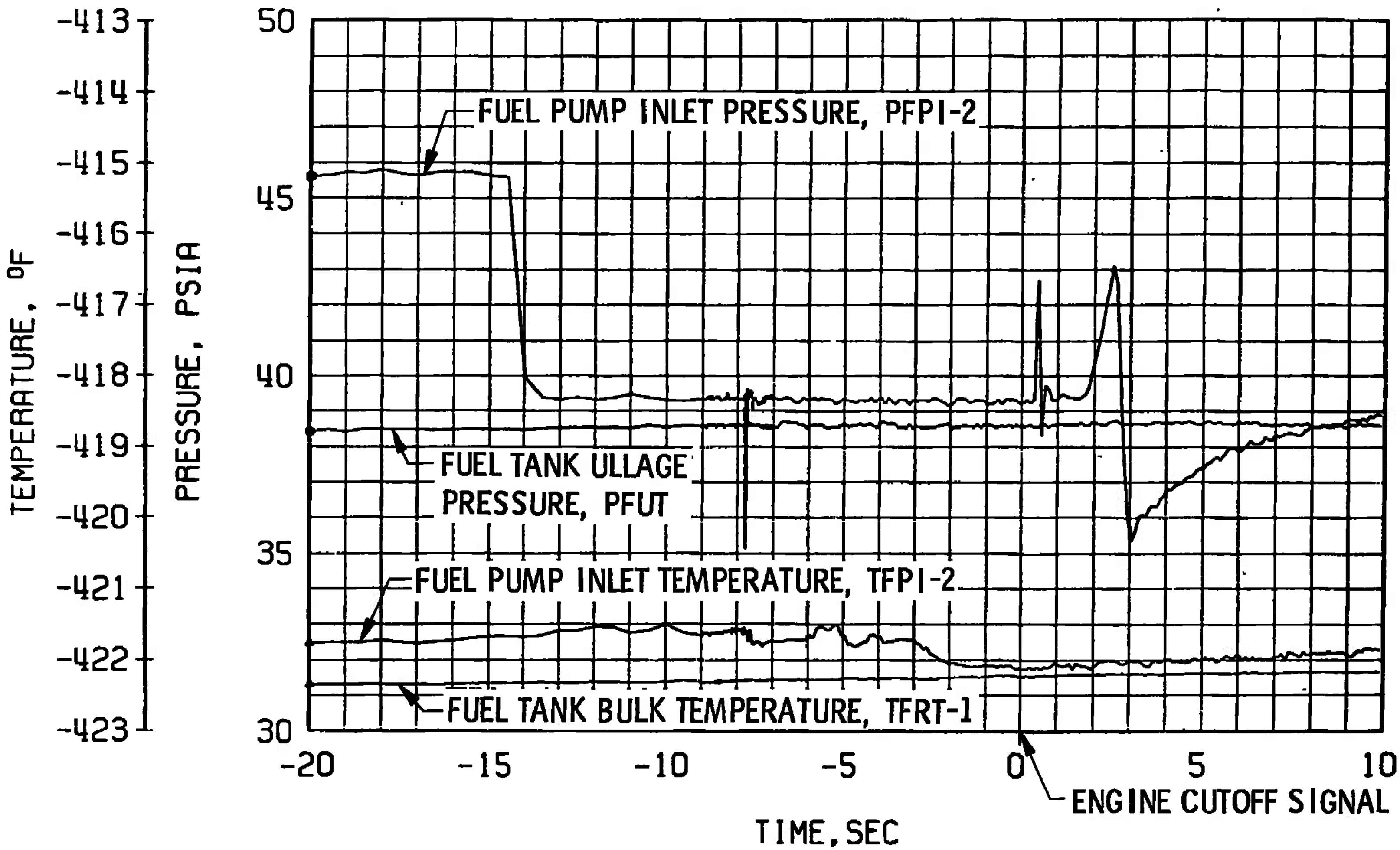


Fig. 12 Fuel Low Pressure Duct Temperature and Pressure Transients, Test 28A

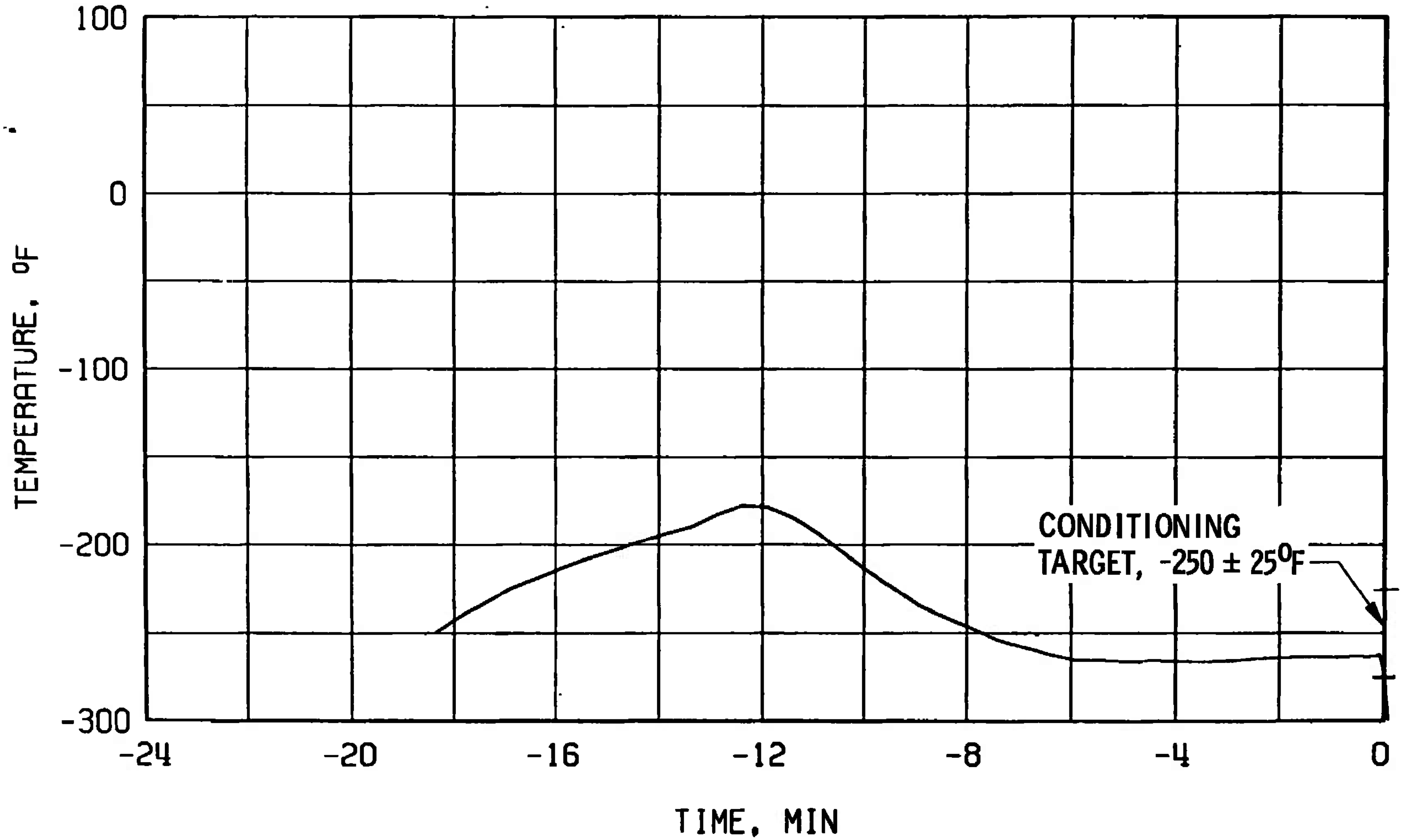


Fig. 13 Thrust Chamber Thermal Conditioning History, Test 28B

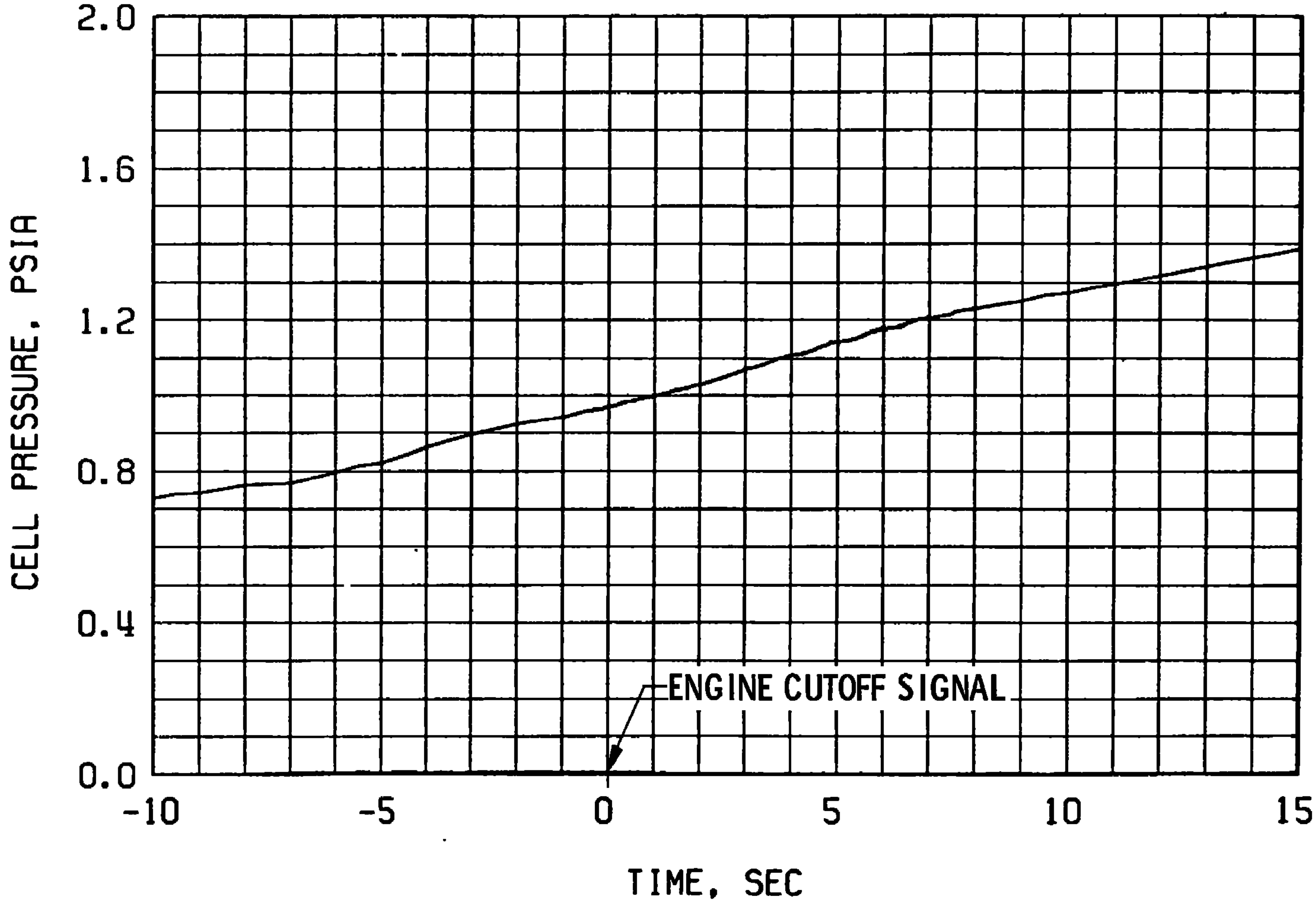


Fig. 14 Engine Ambient Pressure, Test 28B

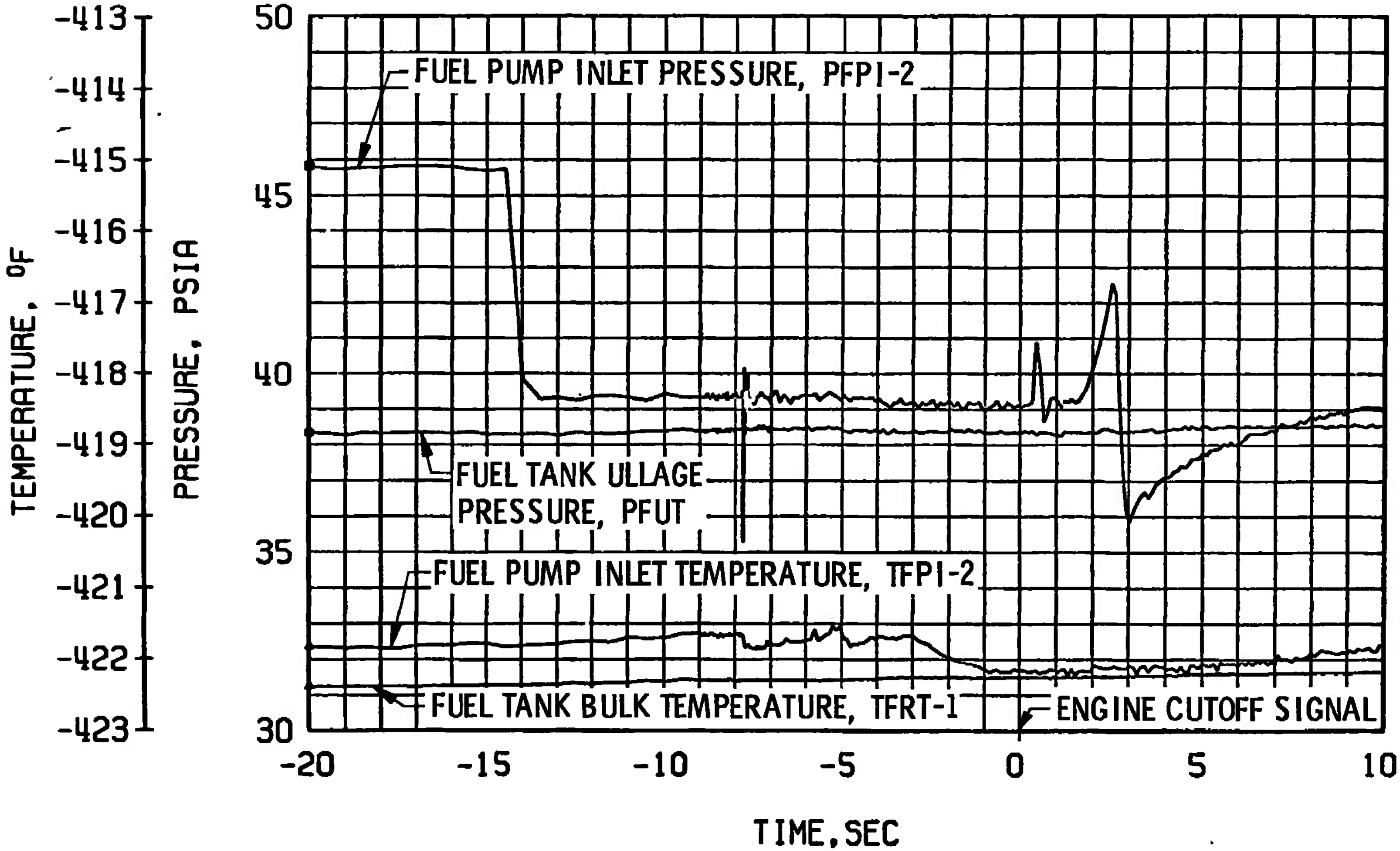


Fig. 15 Fuel Low Pressure Duct Temperature and Pressure Transients, Test 28B

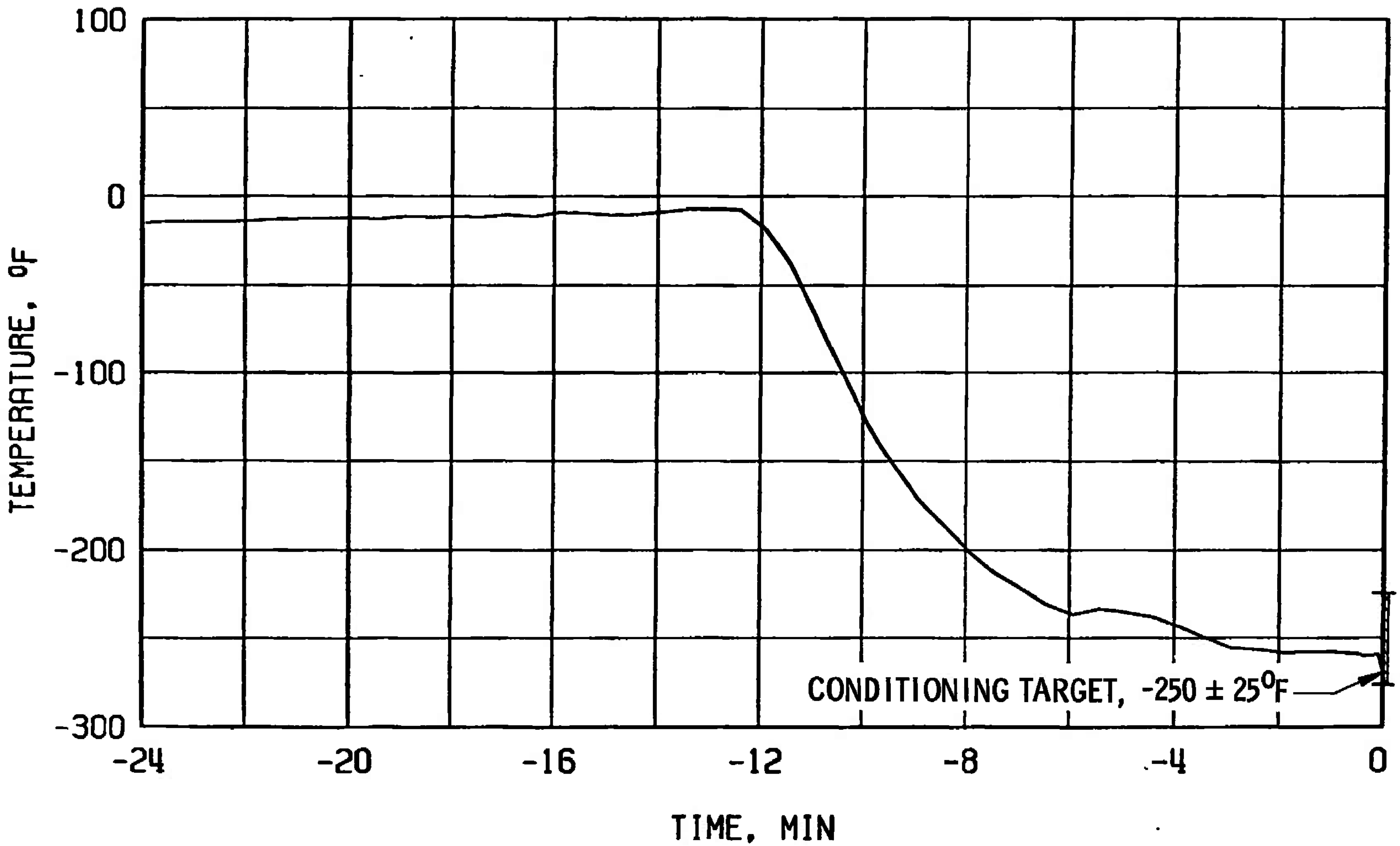


Fig. 16 Thrust Chamber Thermal Conditioning History, Firing 28C

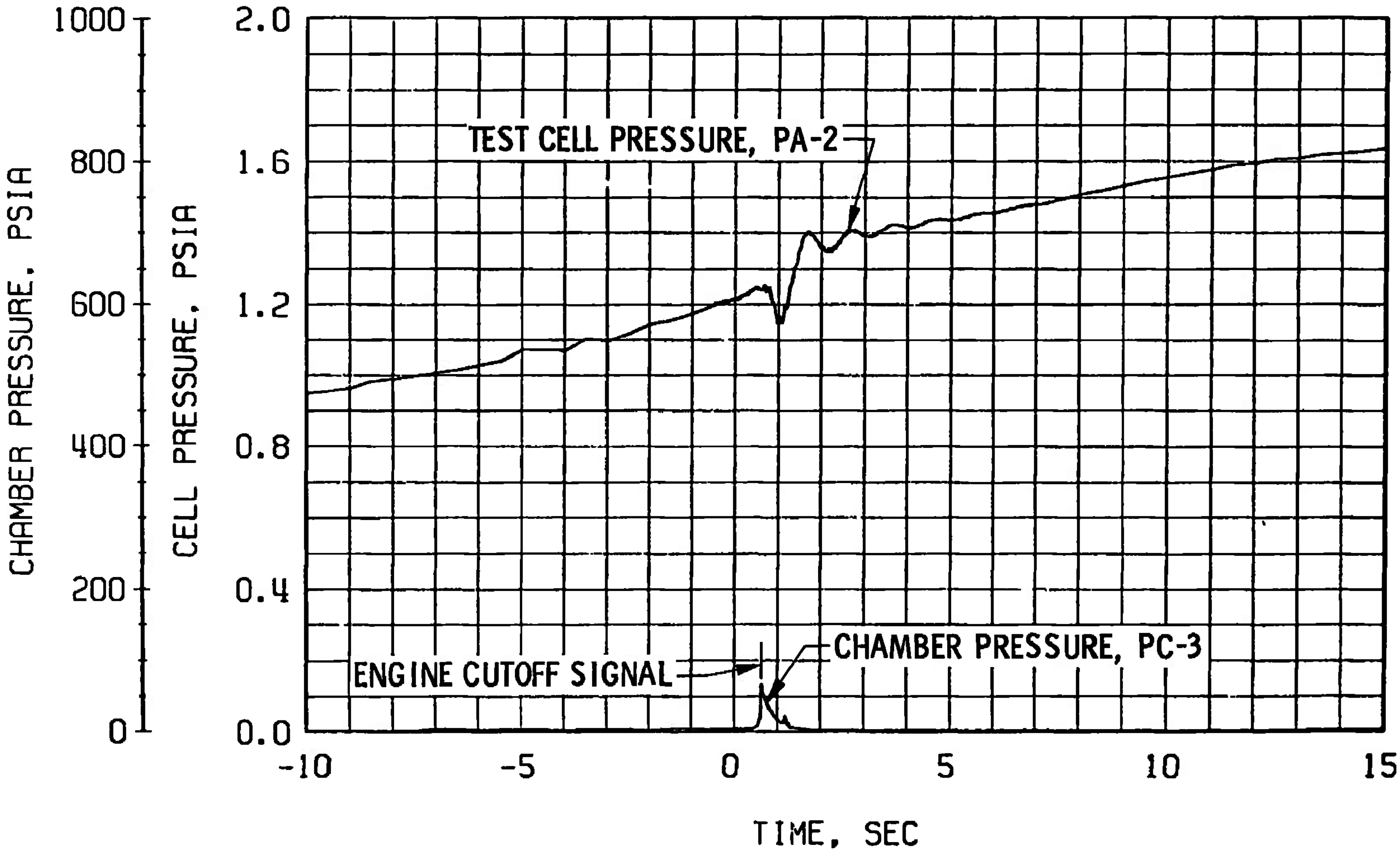
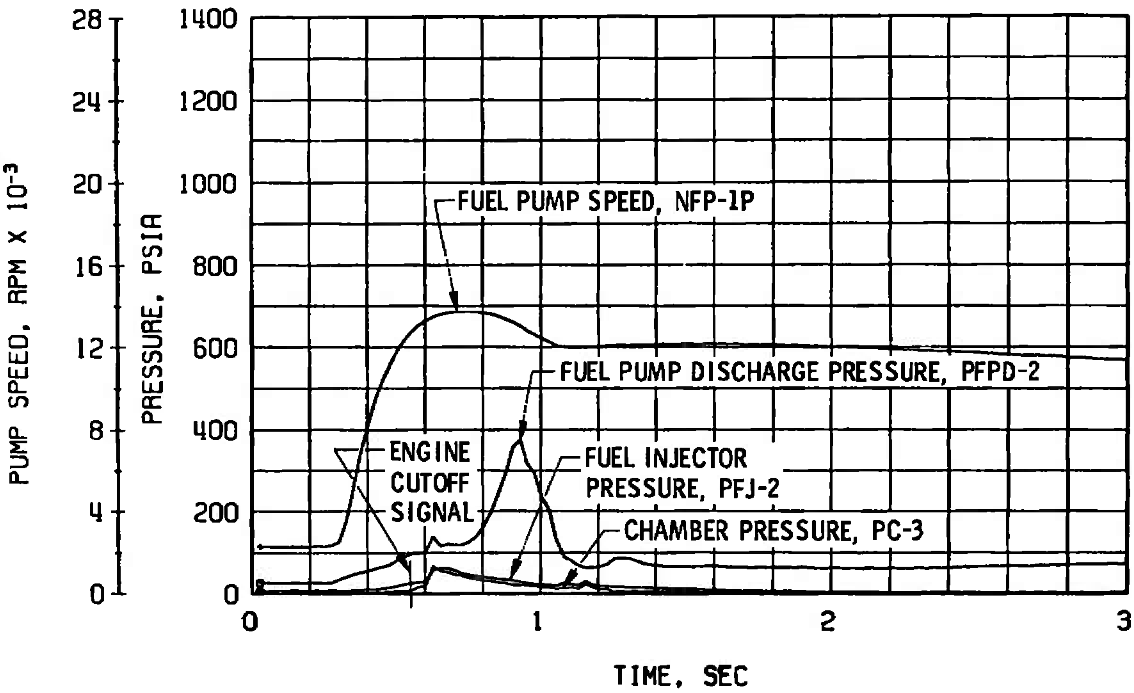
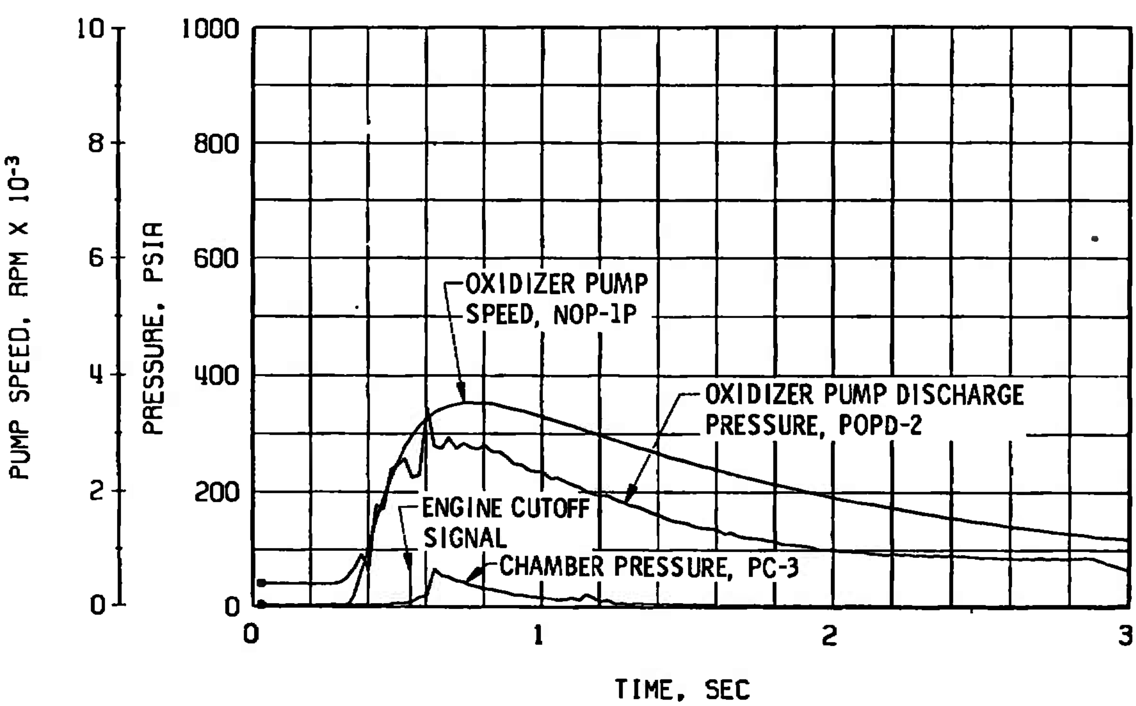


Fig. 17 Engine Ambient and Combustion Chamber Pressures, Firing 28C

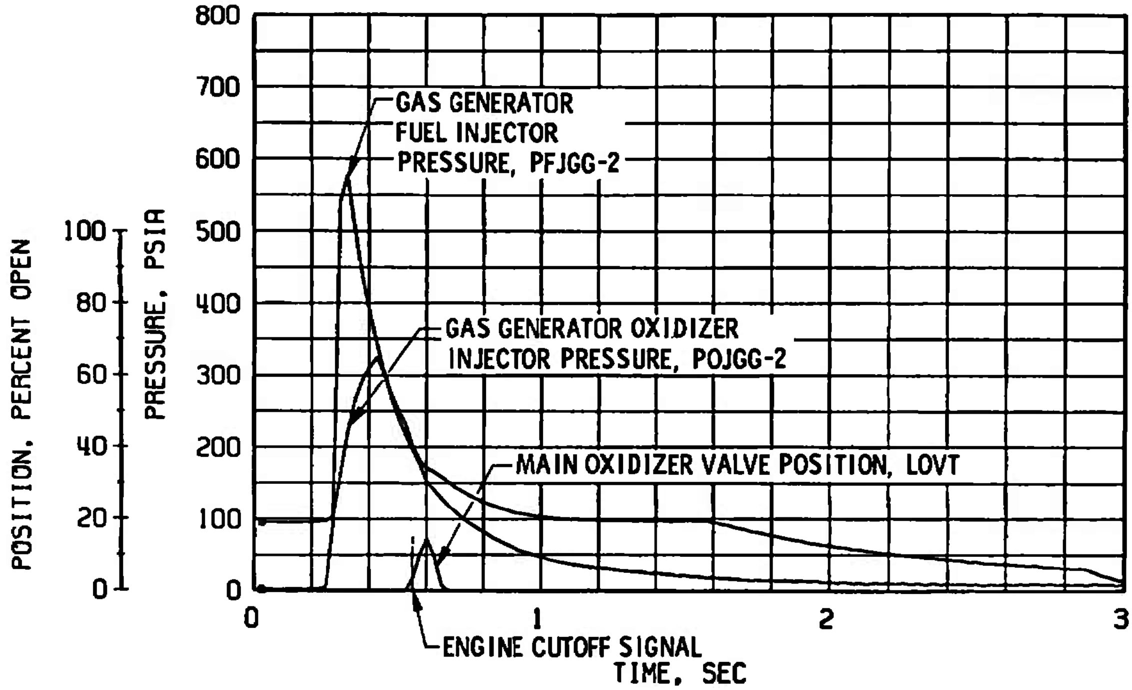


a. Thrust Chamber Fuel System, Start and Shutdown

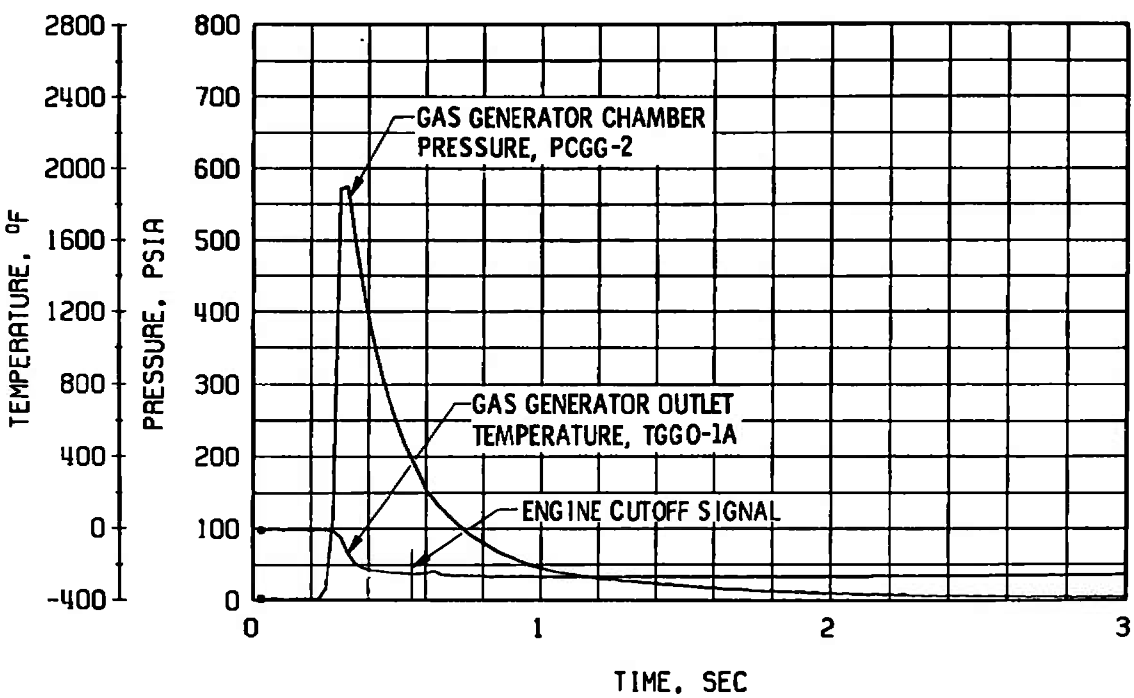


b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 18 Engine Transient Operation, Firing 28C



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 18 Concluded

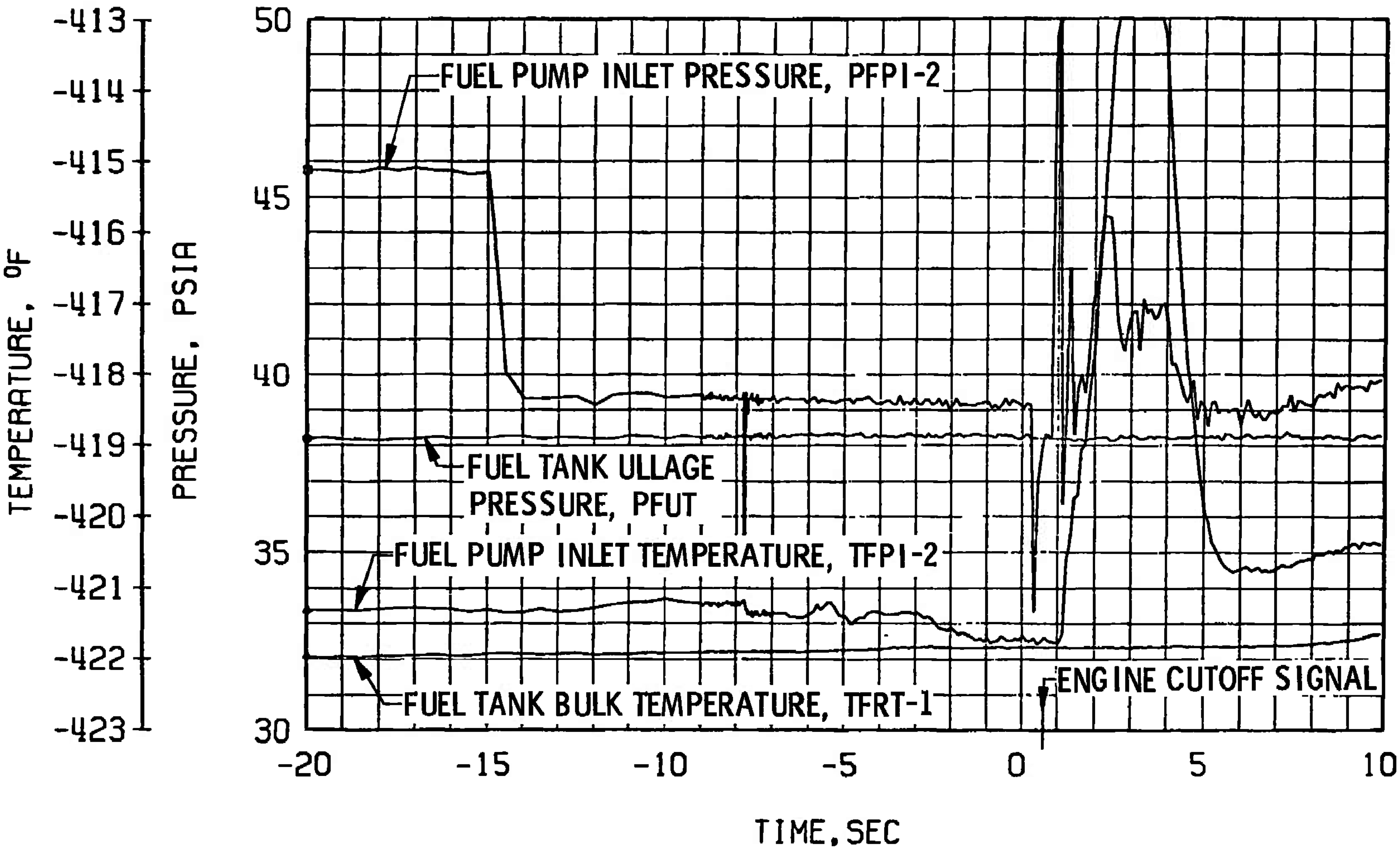
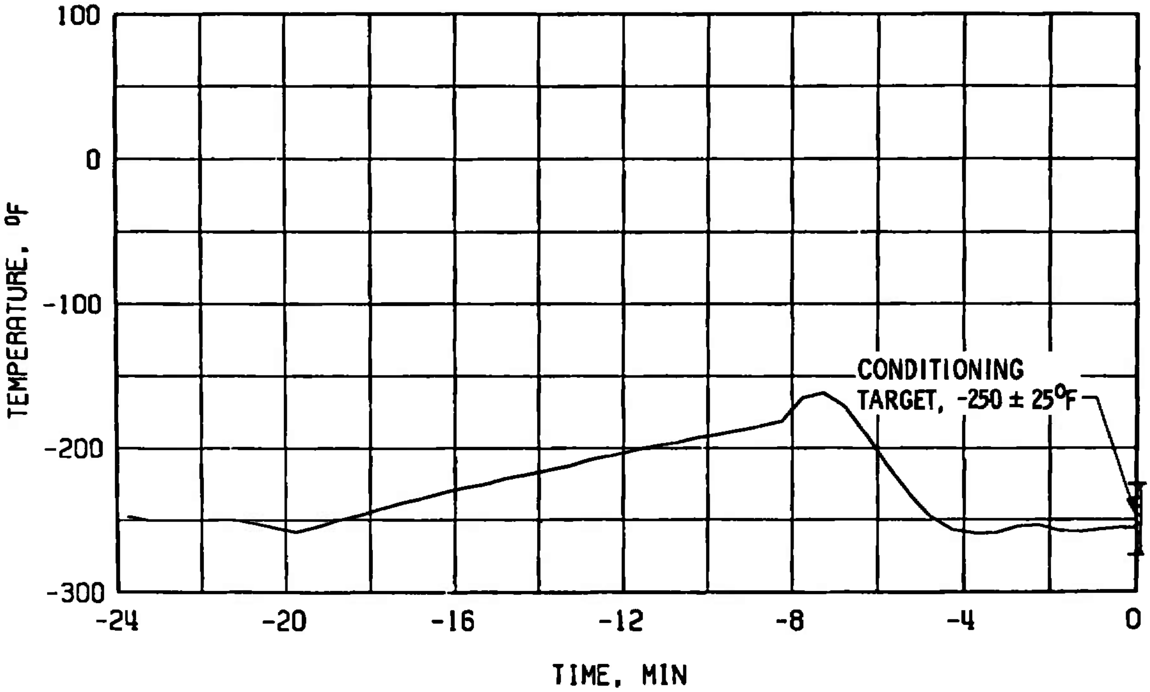
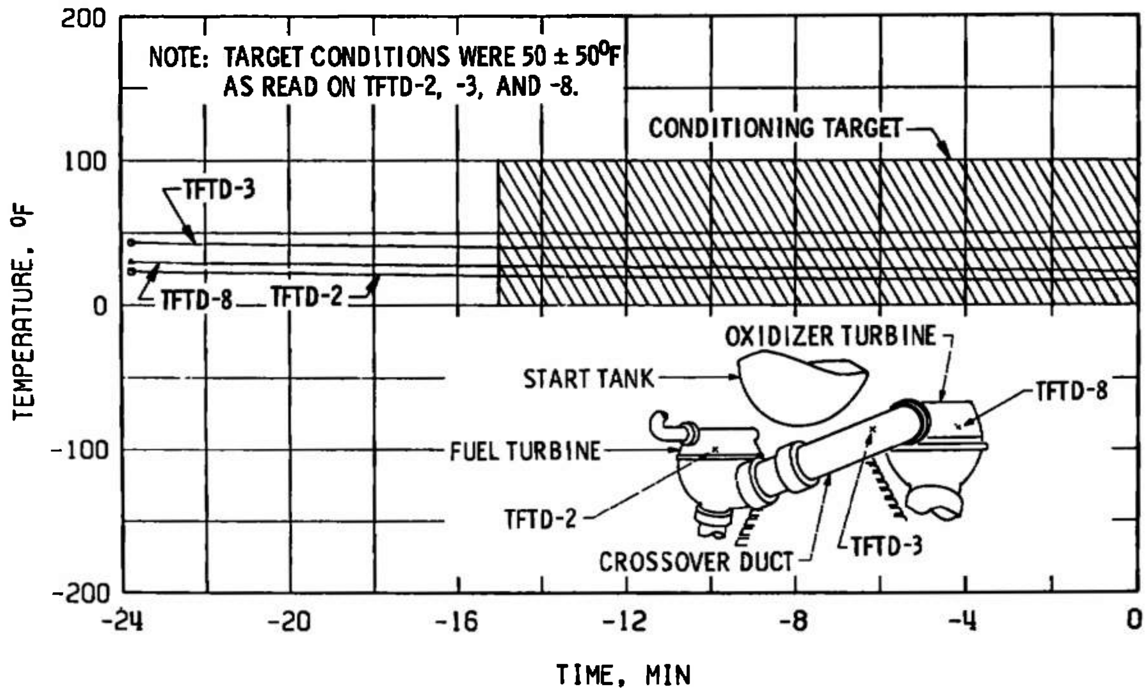


Fig. 19 Fuel Low Pressure Duct Temperature and Pressure Transients, Firing 28C

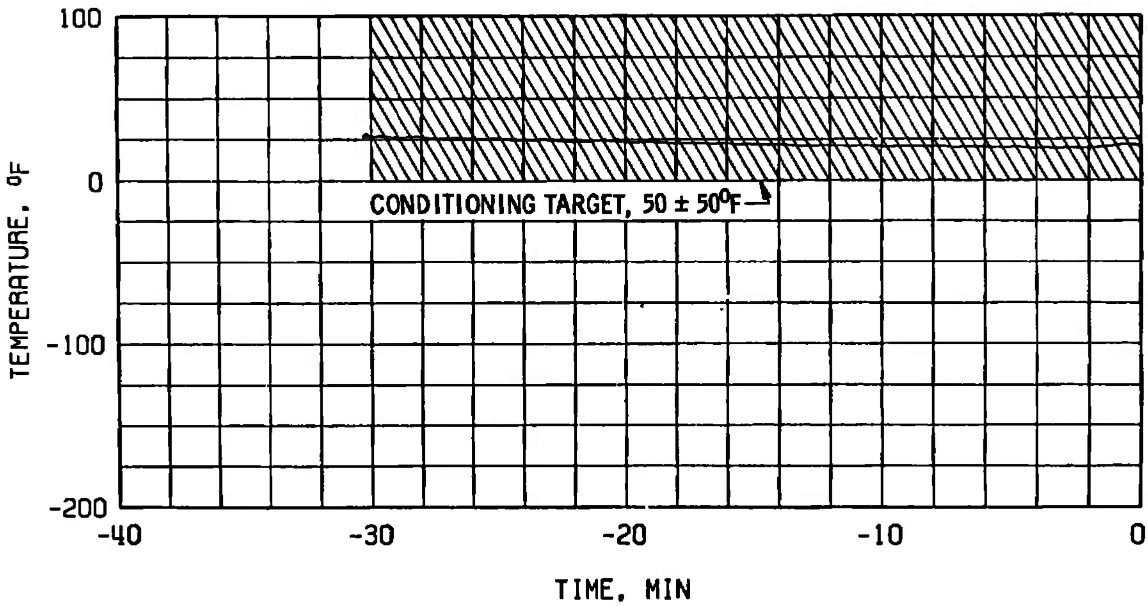


a. Thrust Chamber Throat, TTC-1P

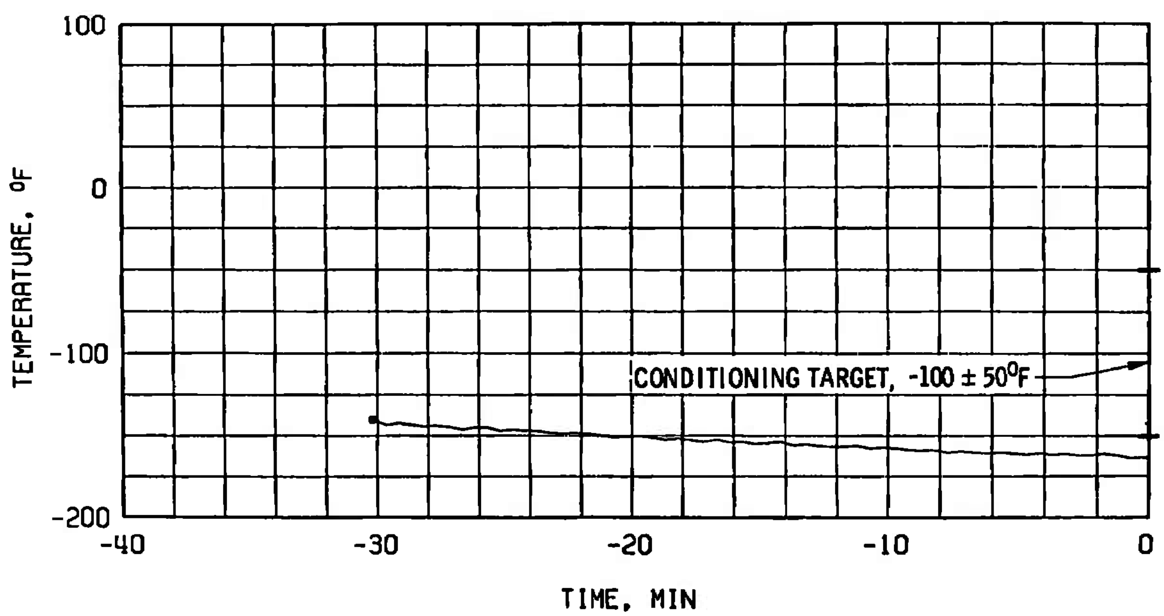


b. Crossover Duct, TFTD

Fig. 20 Thermal Conditioning History of Engine Components, Firing 29A



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 20 Concluded

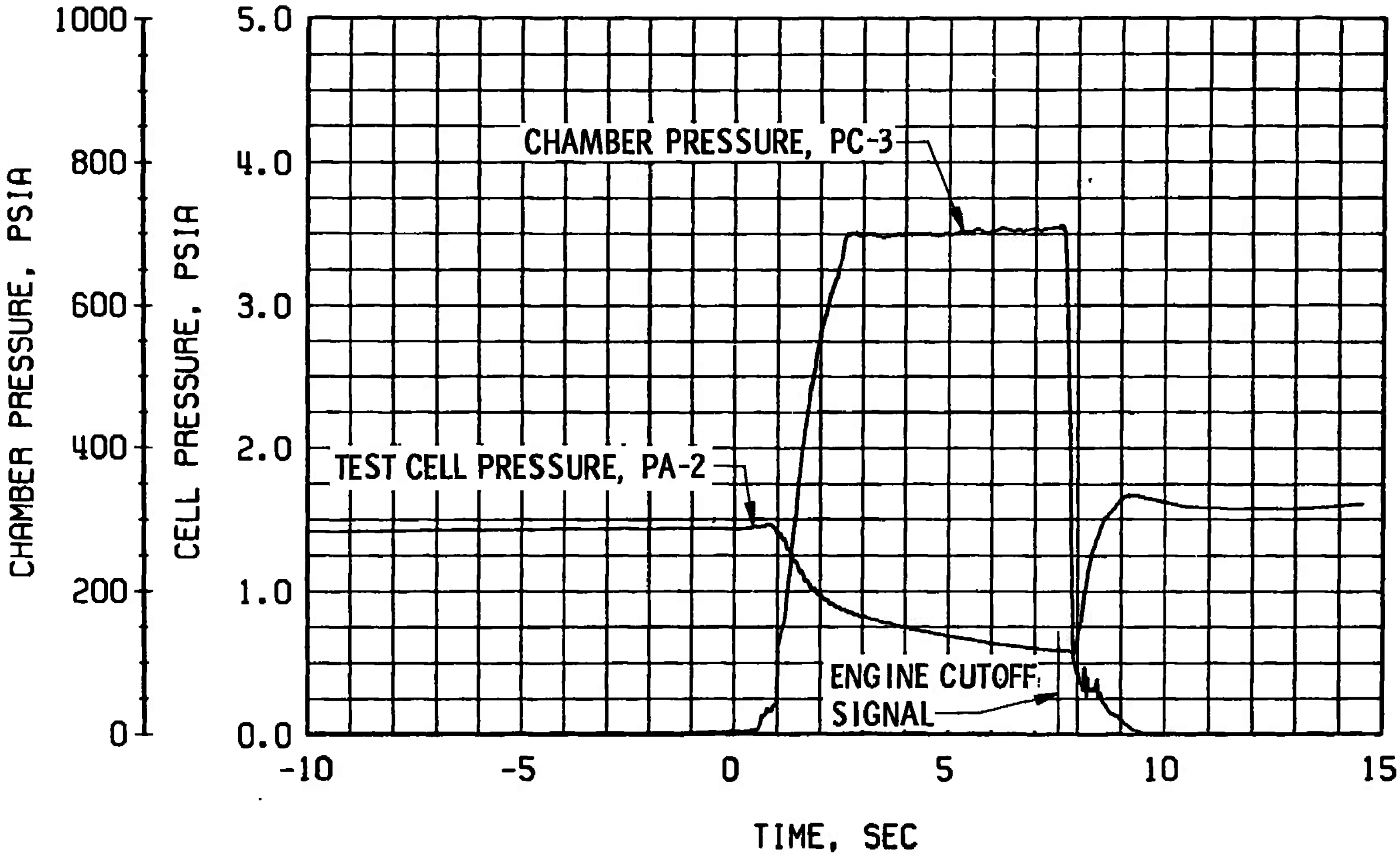
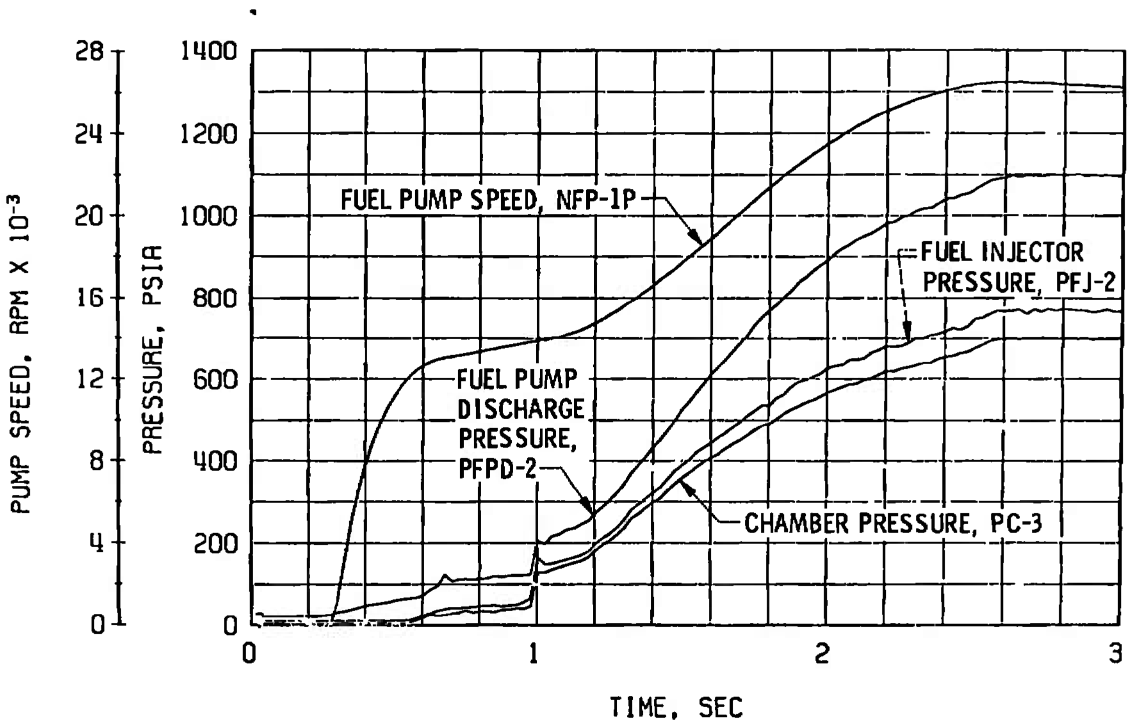
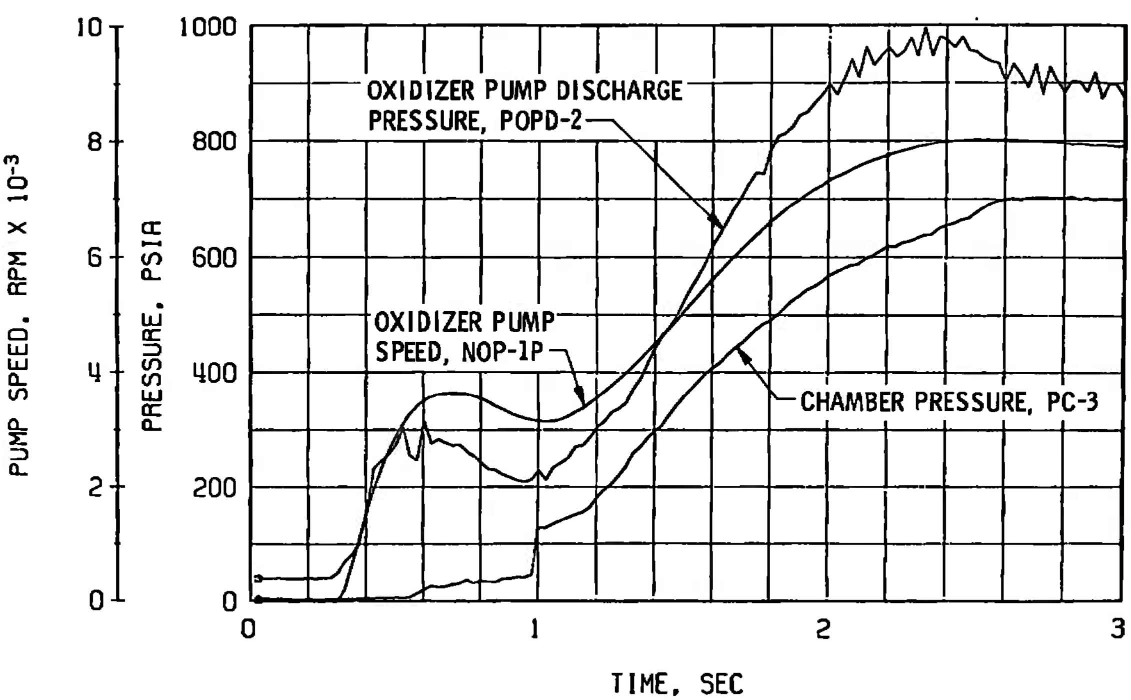


Fig. 21 Engine Ambient and Combustion Chamber Pressures, Firing 29A

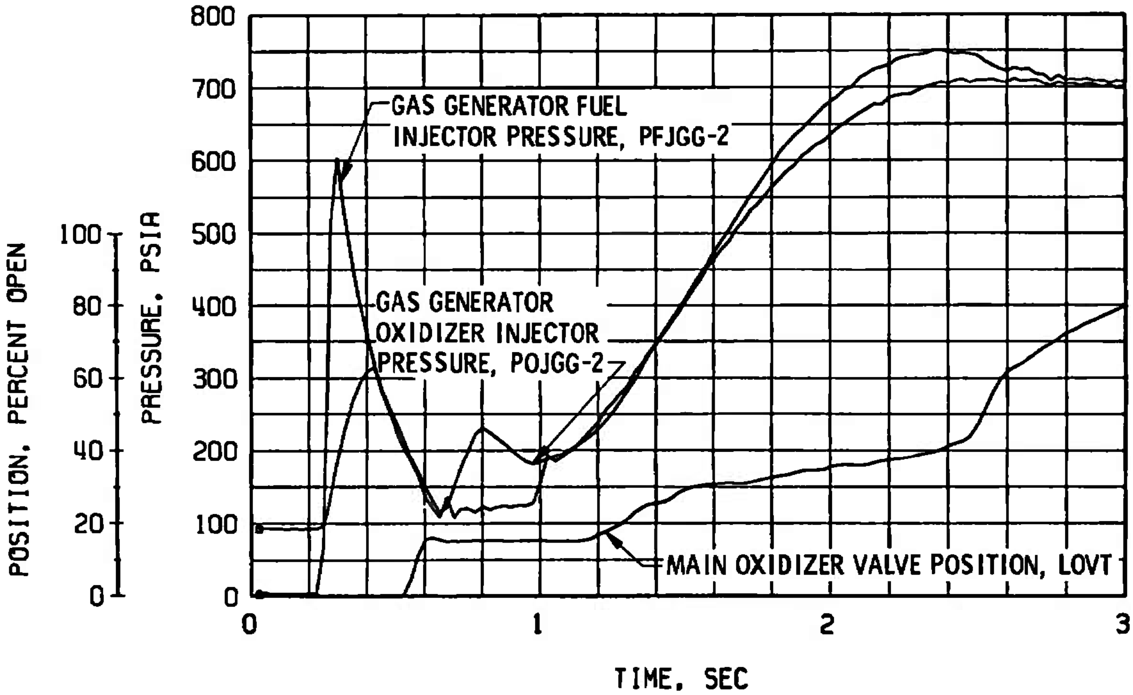


a. Thrust Chamber Fuel System, Start

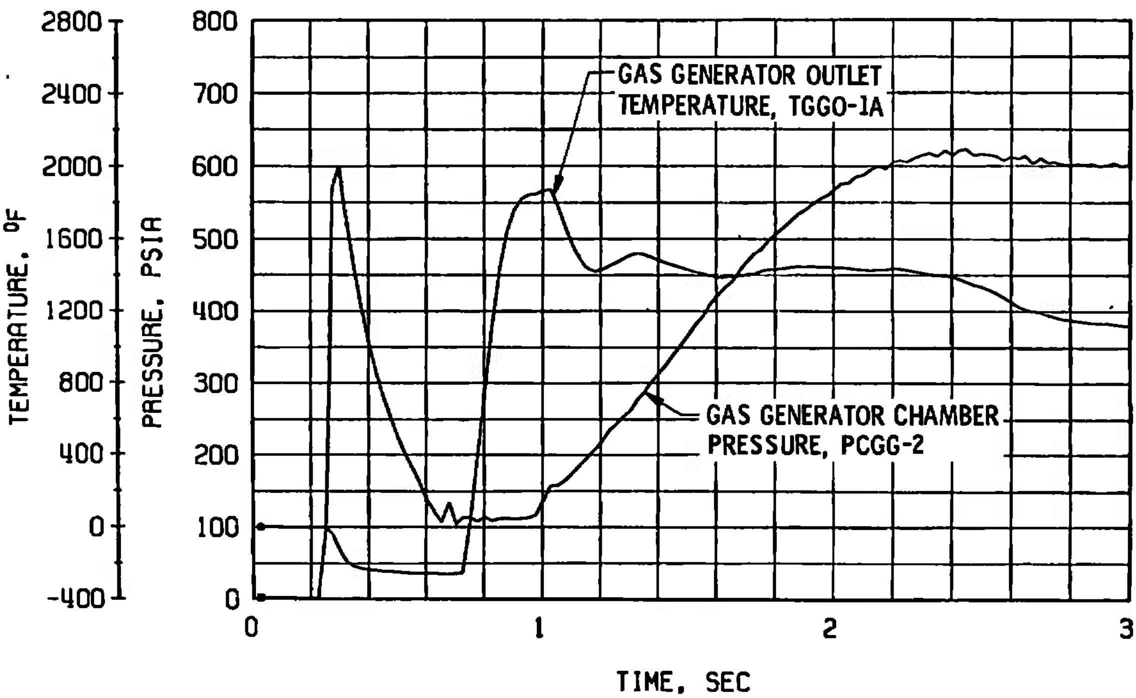


b. Thrust Chamber Oxidizer System, Start

Fig. 22 Engine Transient Operation, Firing 29A

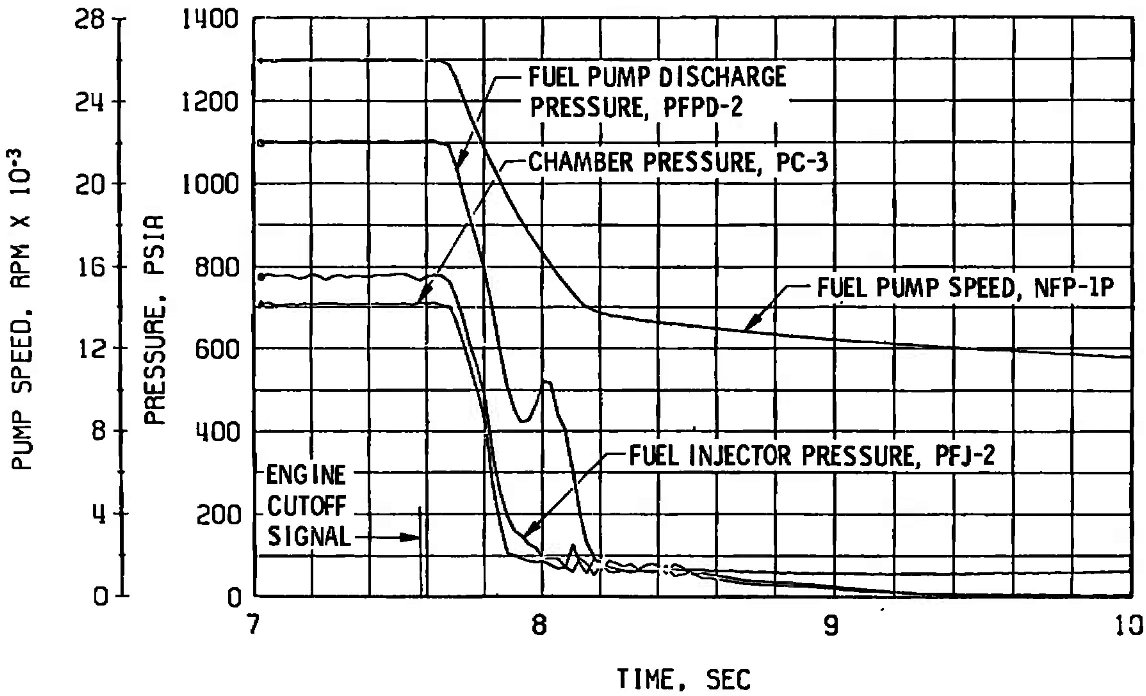


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

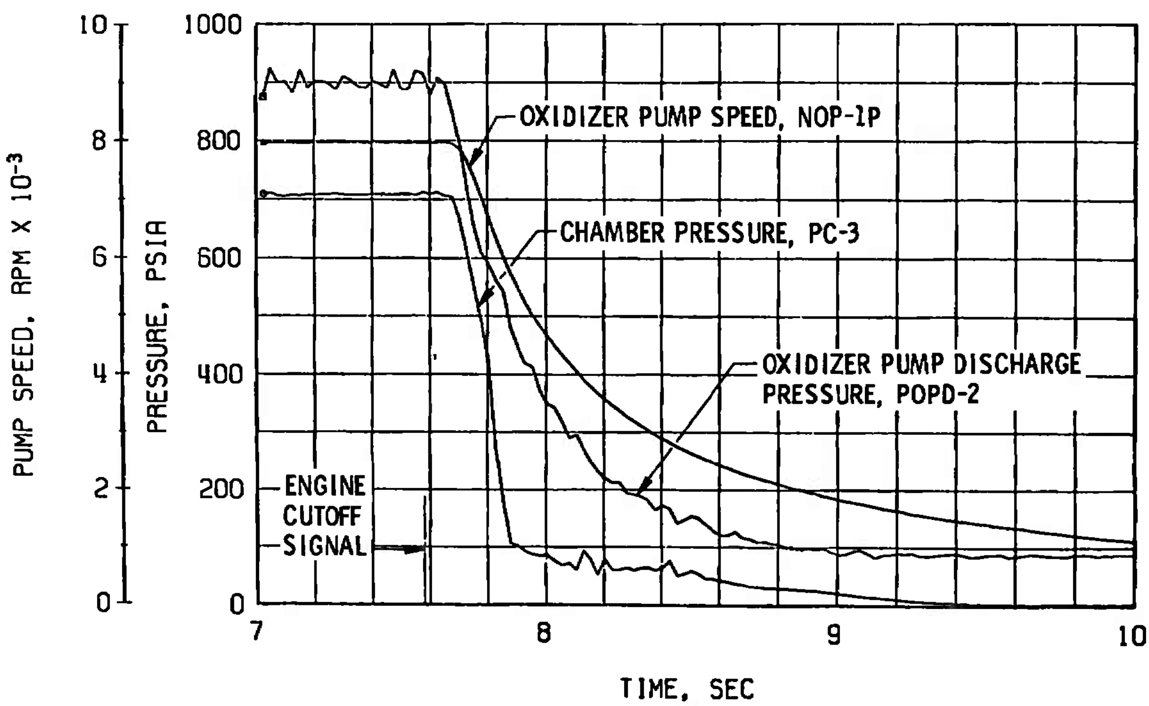


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 22 Continued

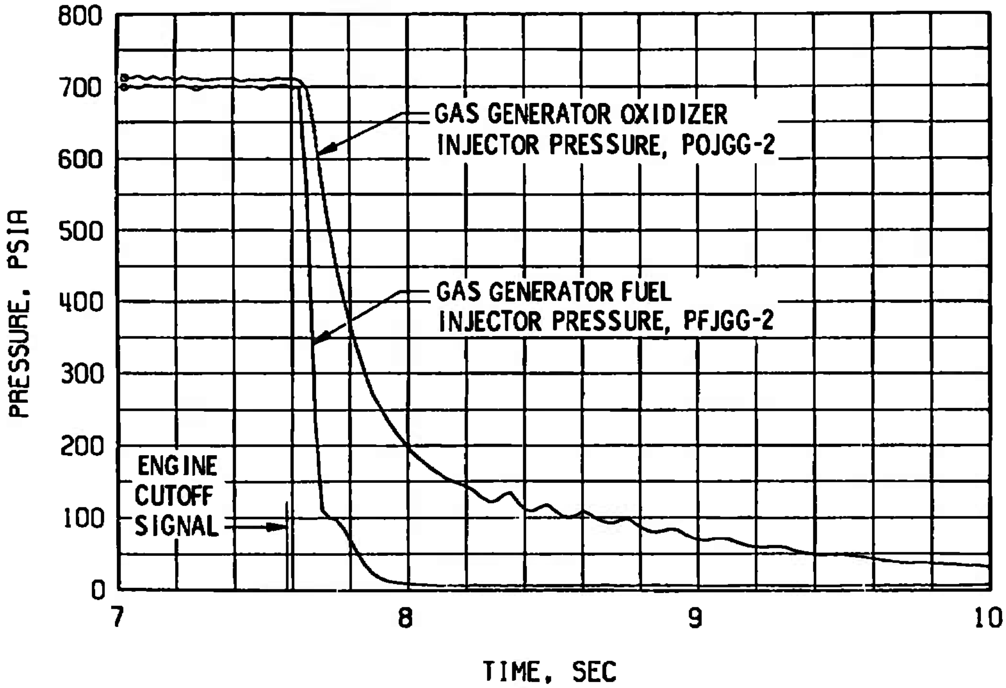


e. Thrust Chamber Fuel System, Shutdown

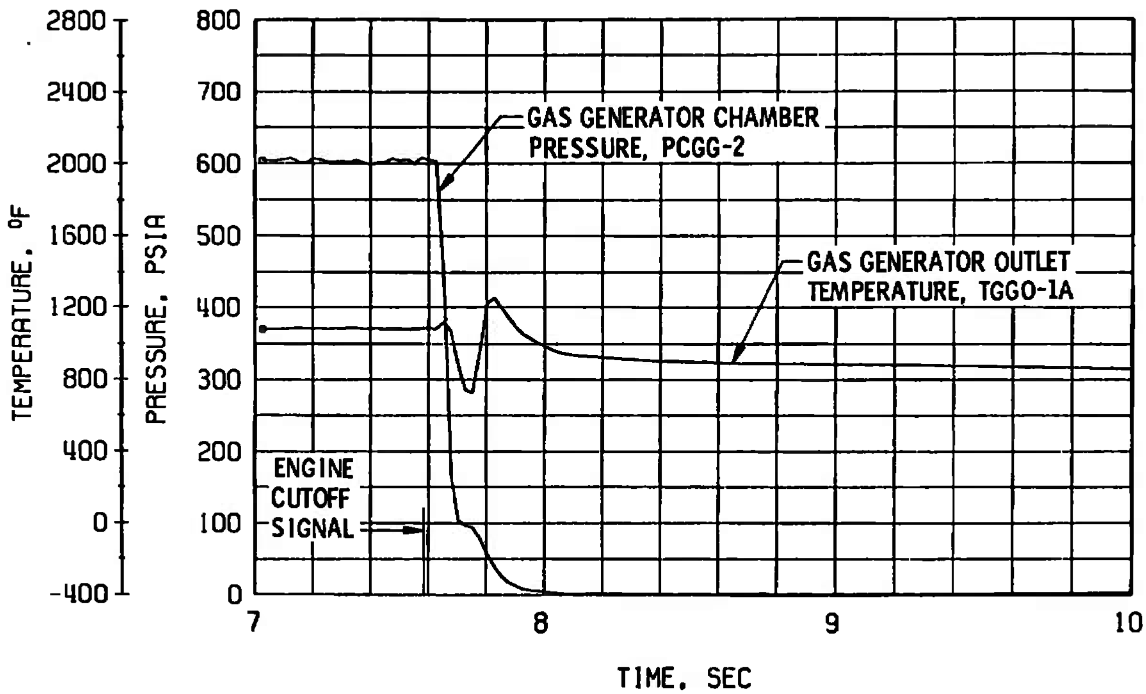


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 22 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 22 Concluded

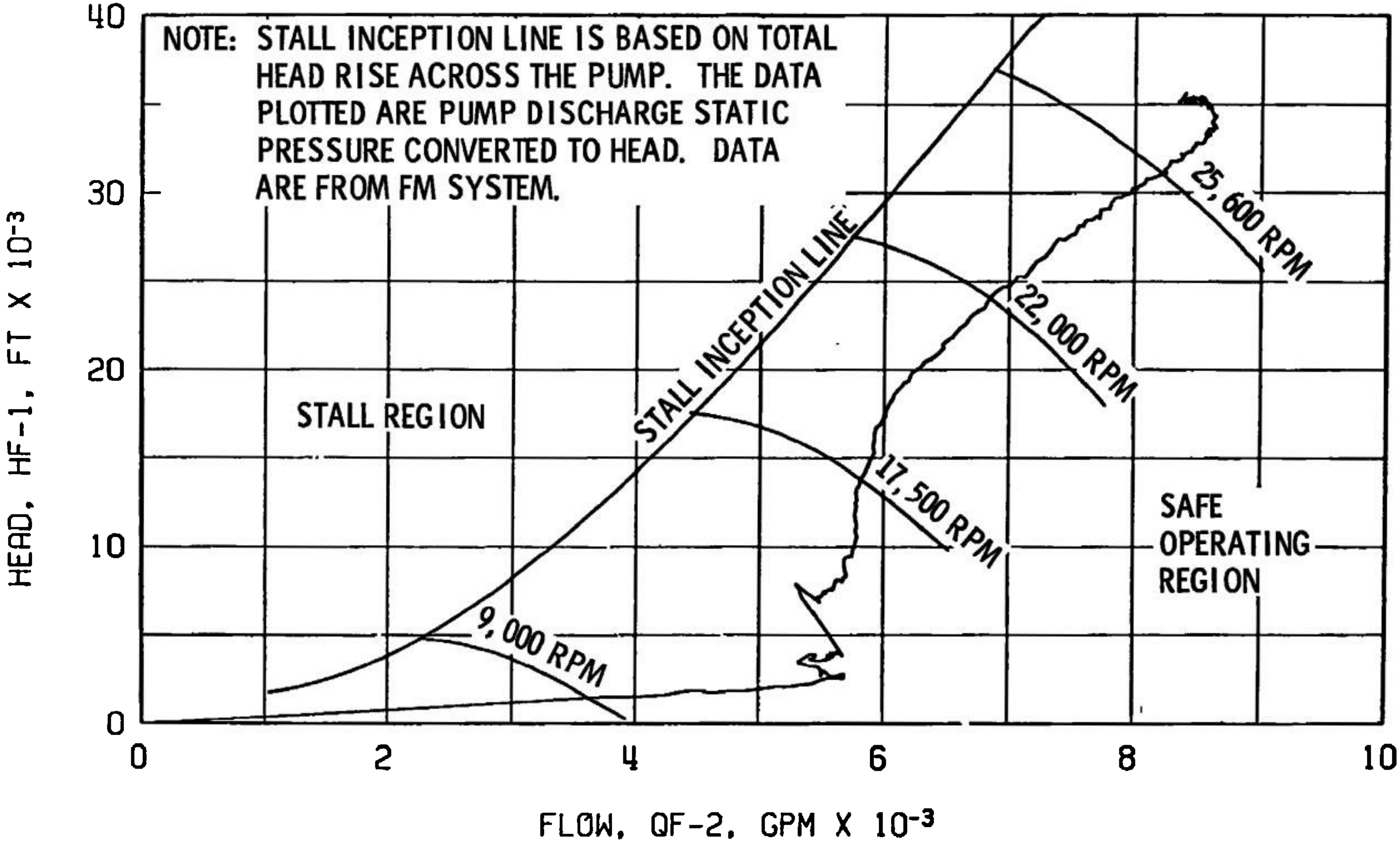
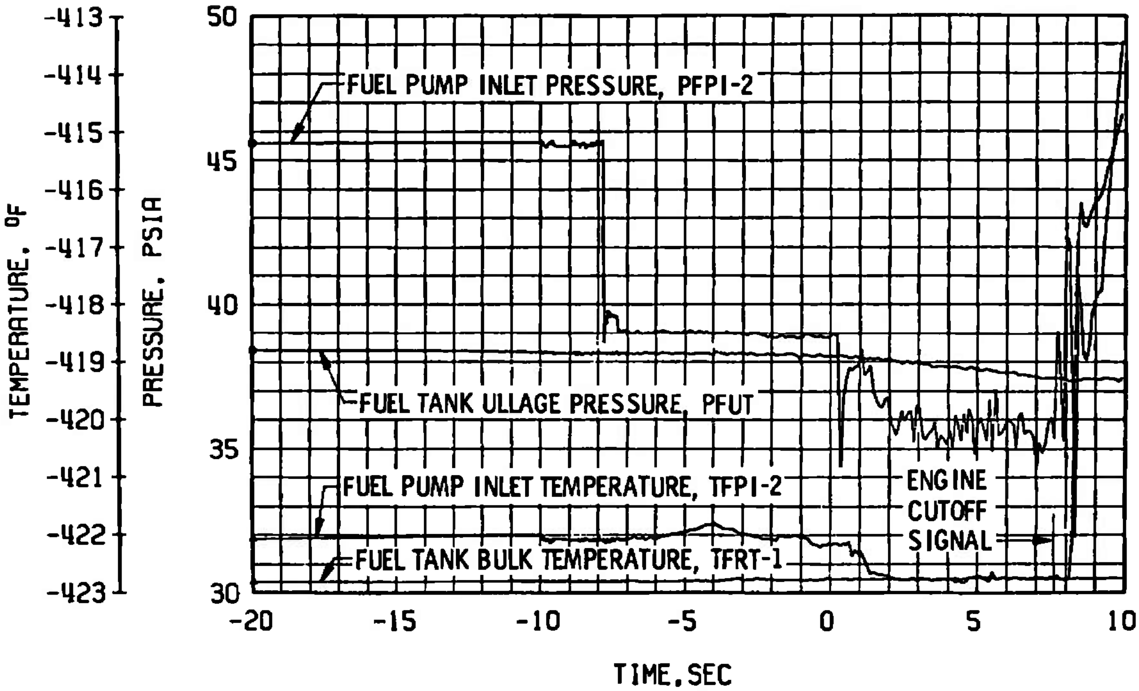
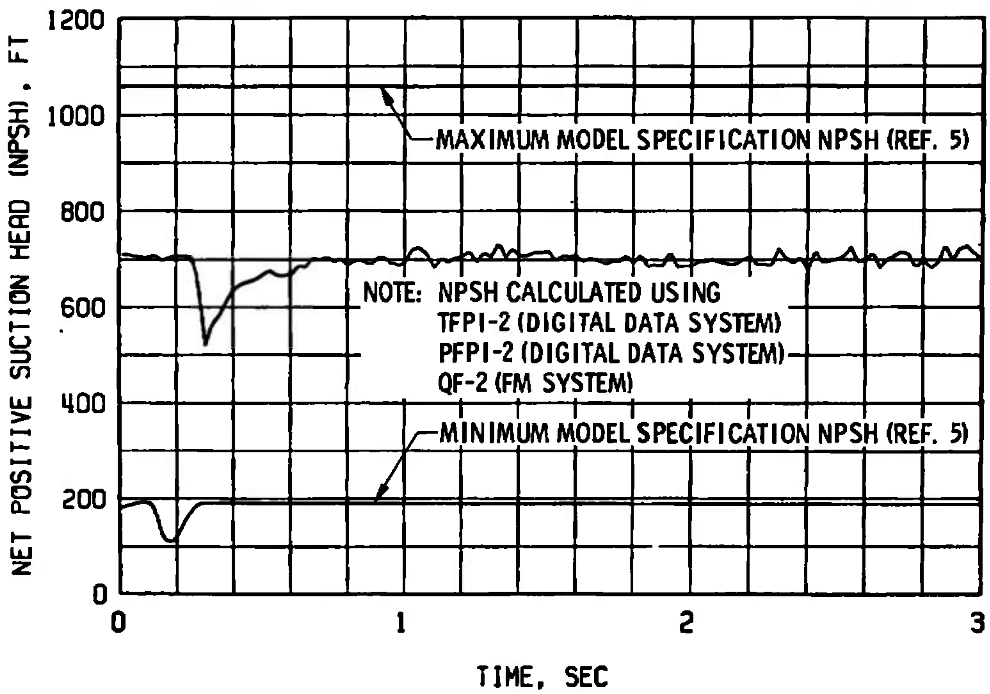


Fig. 23 Fuel Pump Stall Transient Performance, Firing 29A

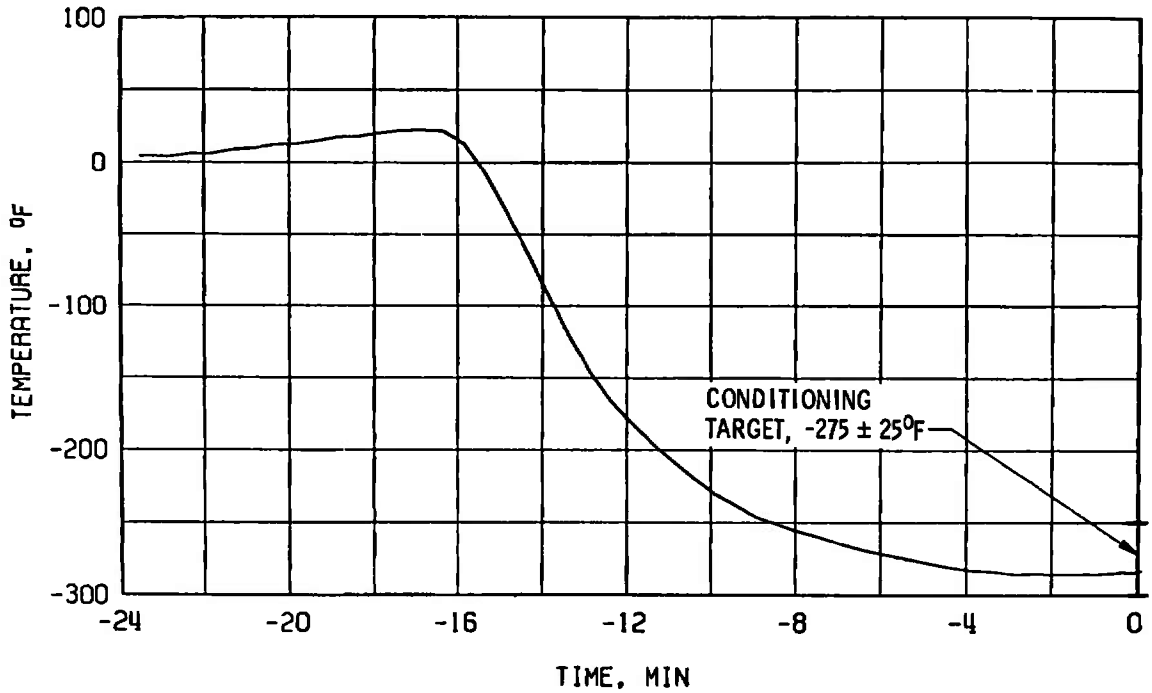


a. Duct Pressure and Temperature Transients

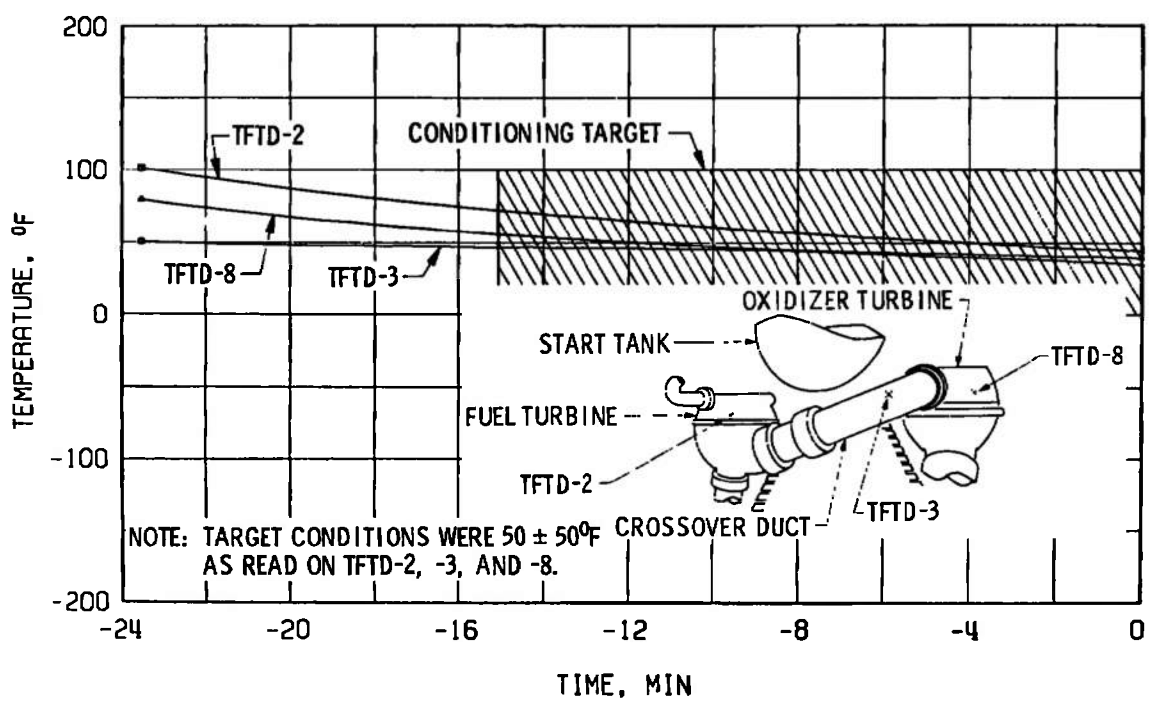


b. Fuel Pump NPSH during Start Transient, Firing 29A

Fig. 24 Fuel Low Pressure Duct Performance, Firing 29A

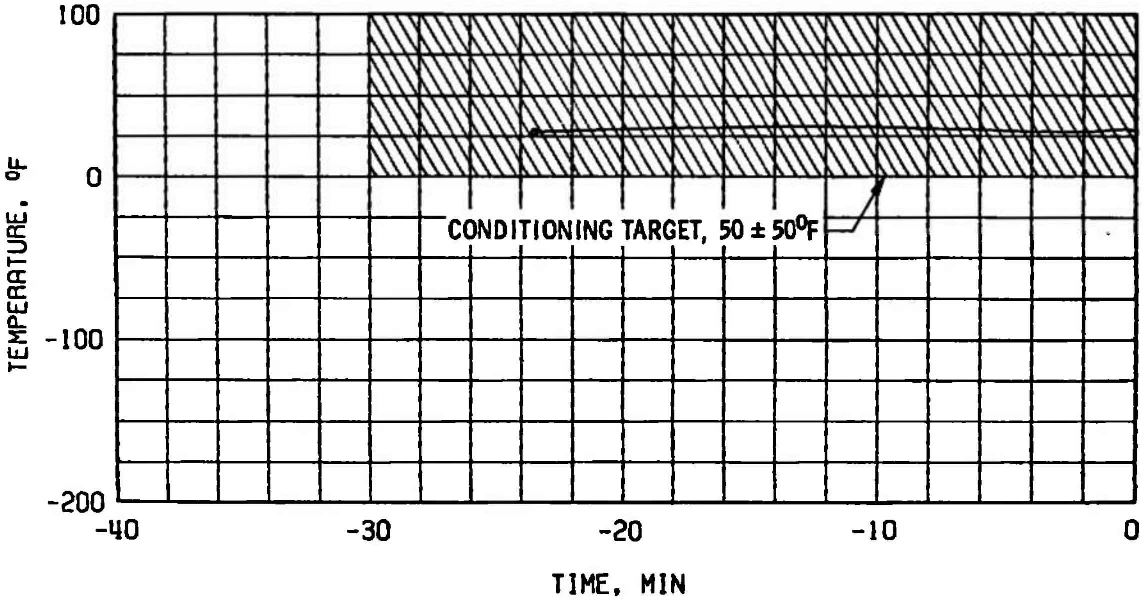


a. Thrust Chamber Throat, TTC-1P

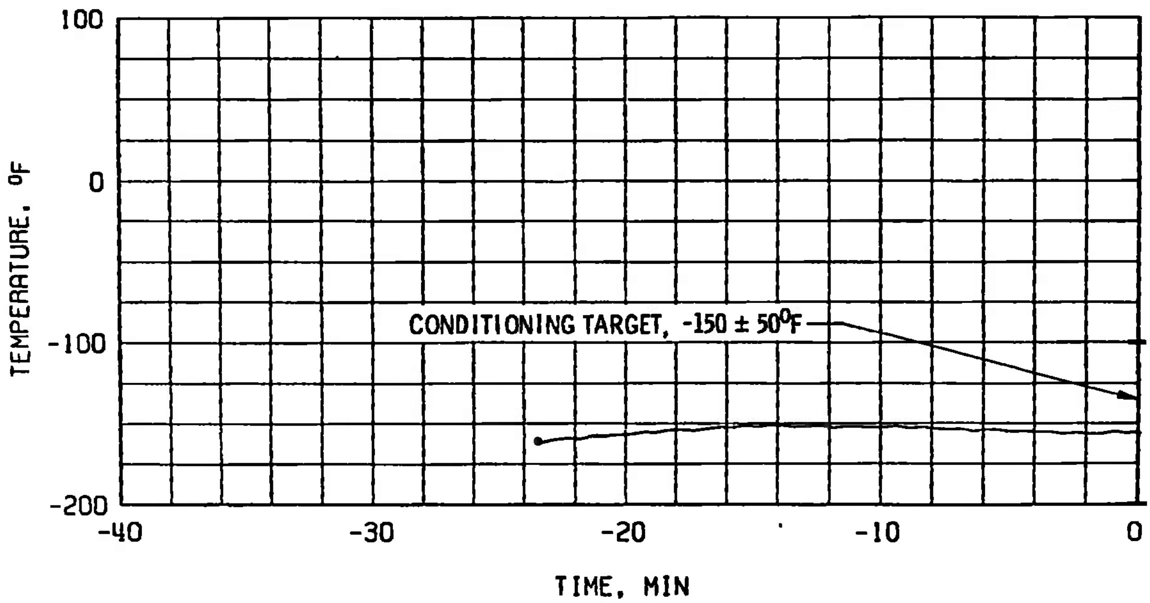


b. Crossover Duct, TFTD

Fig. 25 Thermal Conditioning History of Engine Components, Firing 29B



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 25 Concluded

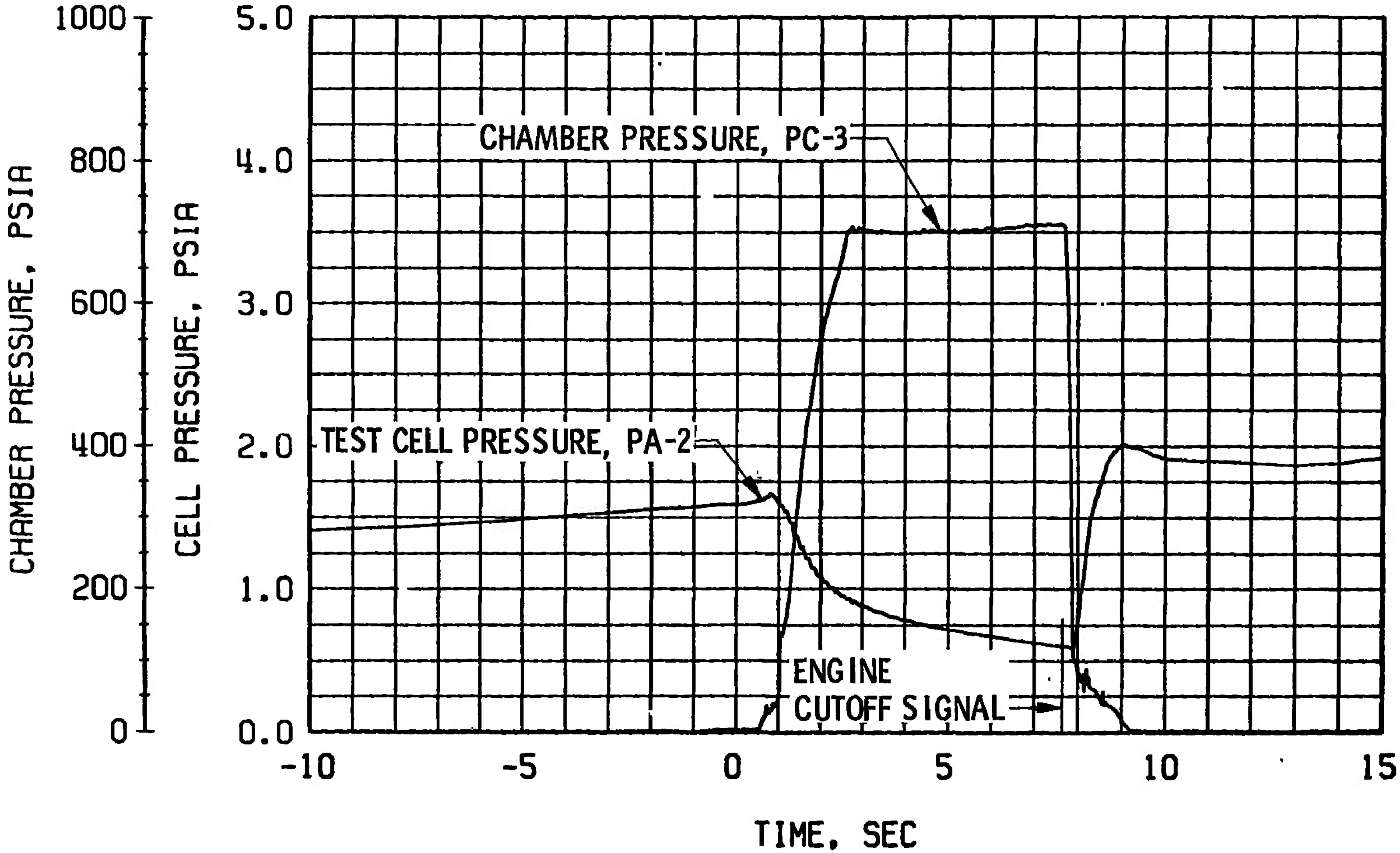
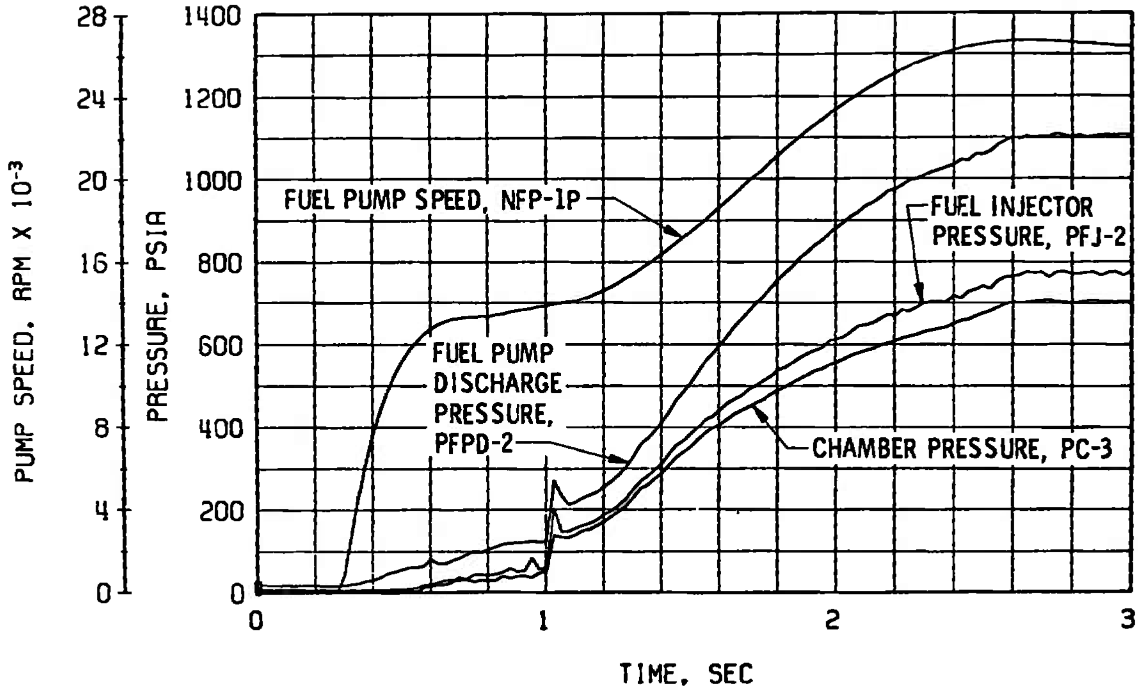
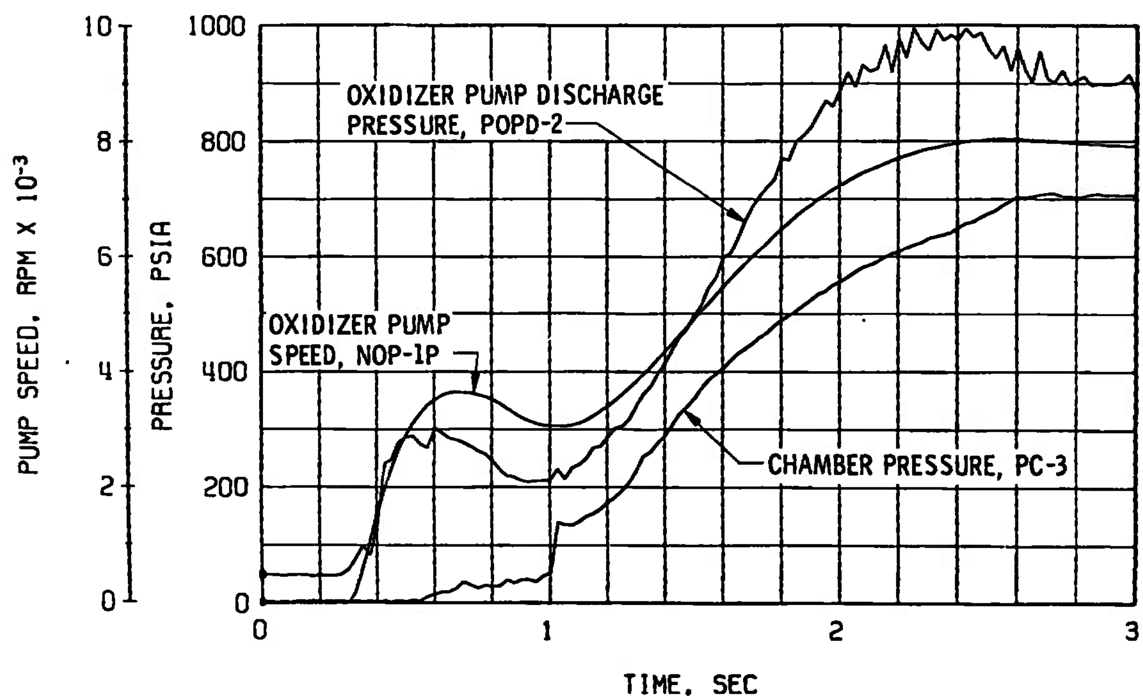


Fig. 26 Engine Ambient and Combustion Chamber Pressures, Firing 29B

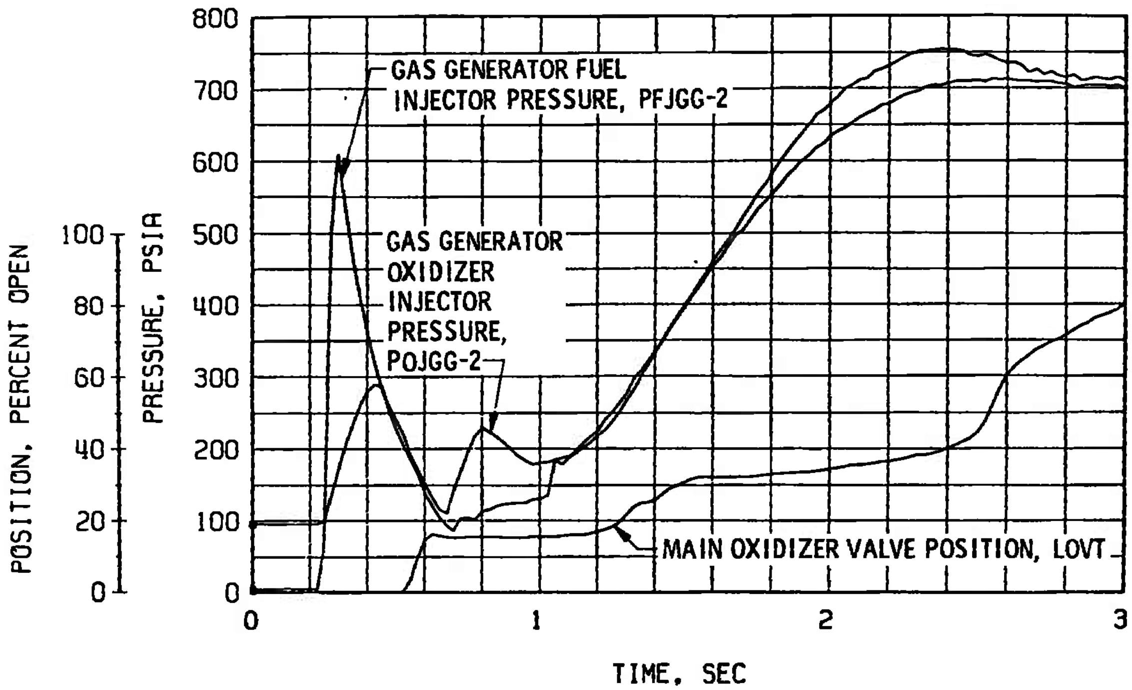


a. Thrust Chamber Fuel System, Start

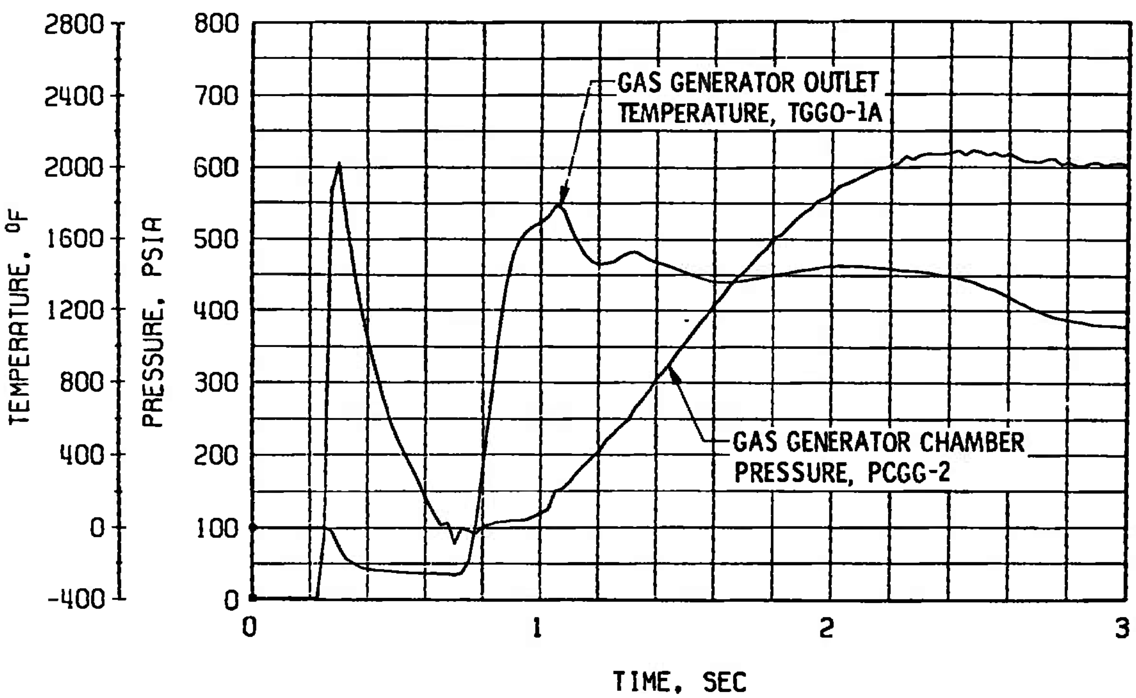


b. Thrust Chamber Oxidizer System, Start

Fig. 27 Engine Transient Operation, Firing 29B

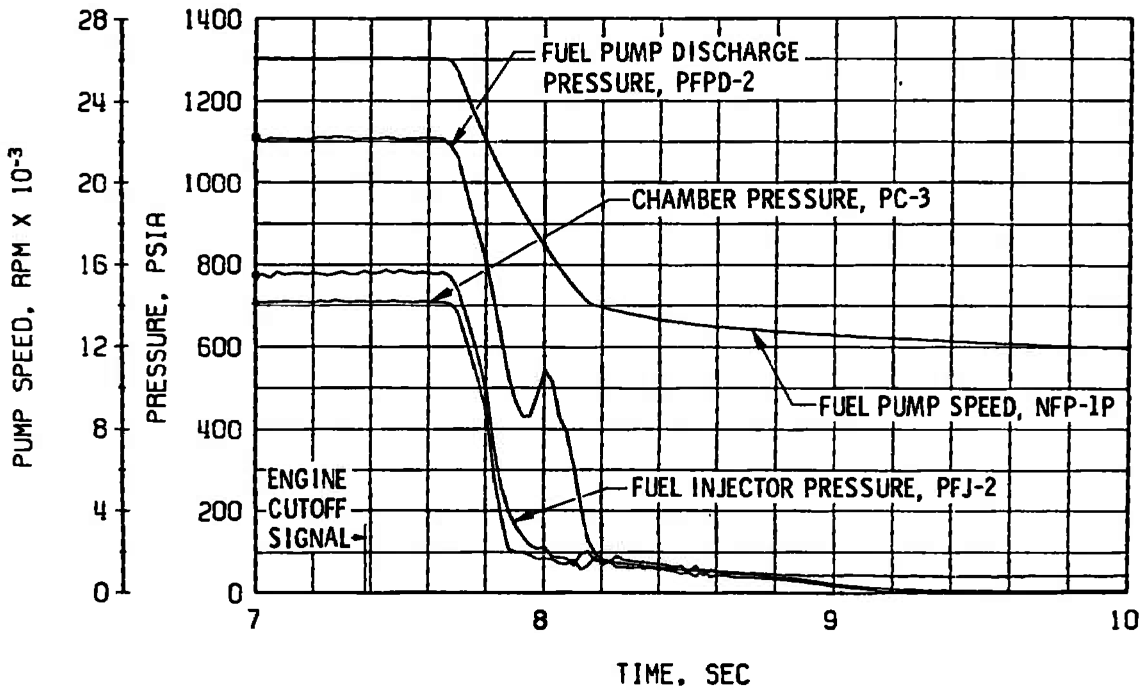


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

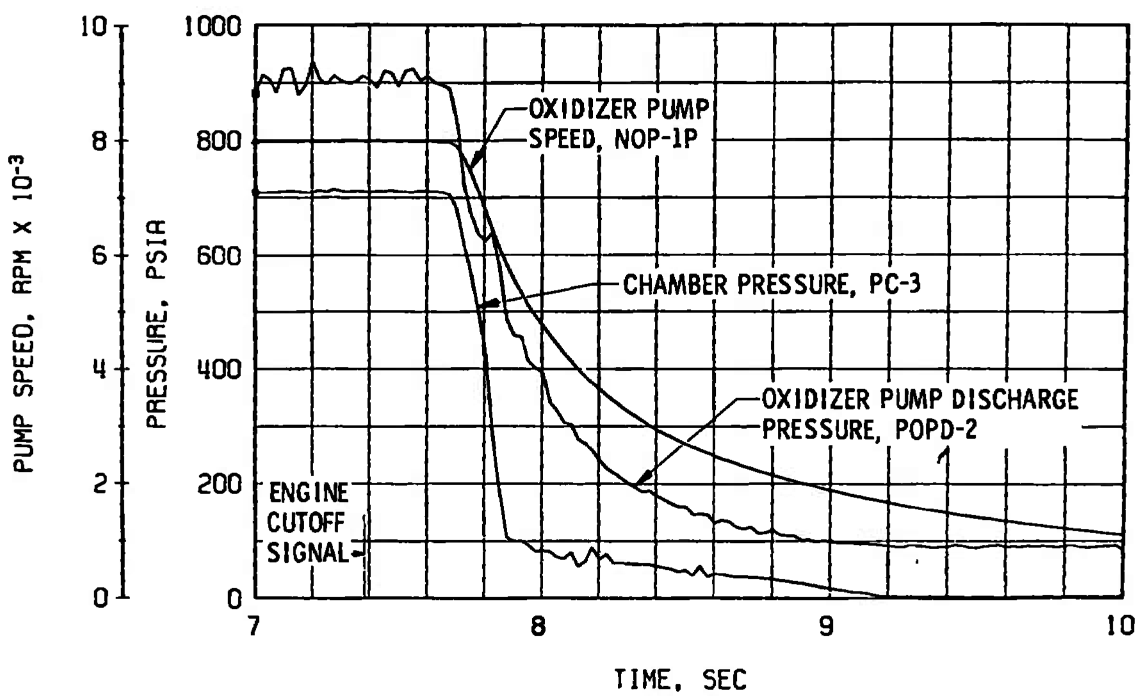


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 27 Continued

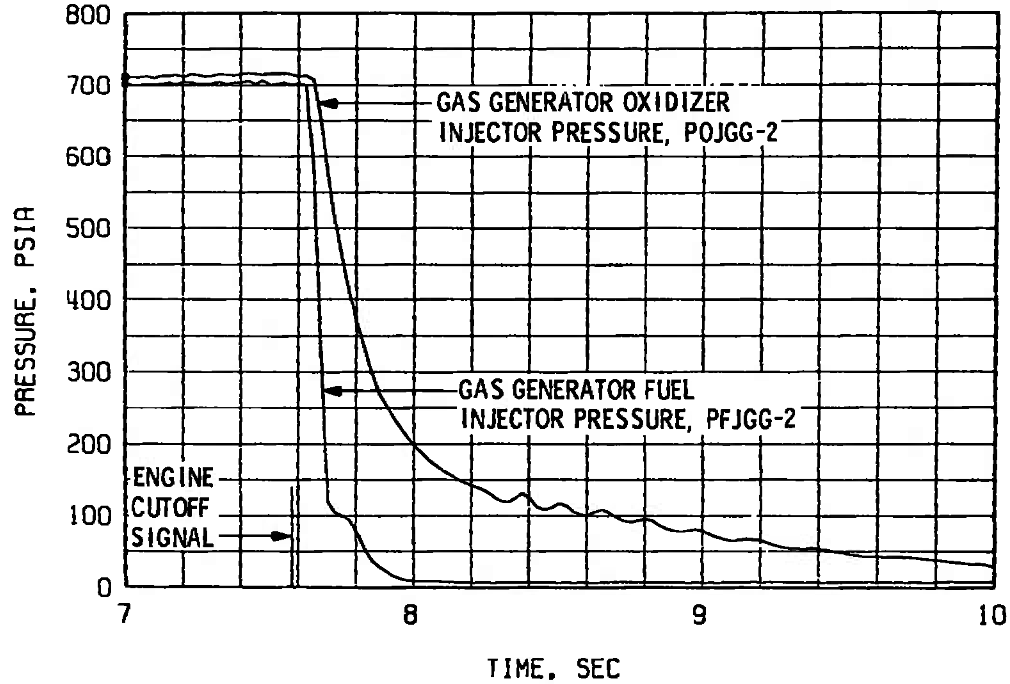


e. Thrust Chamber Fuel System, Shutdown

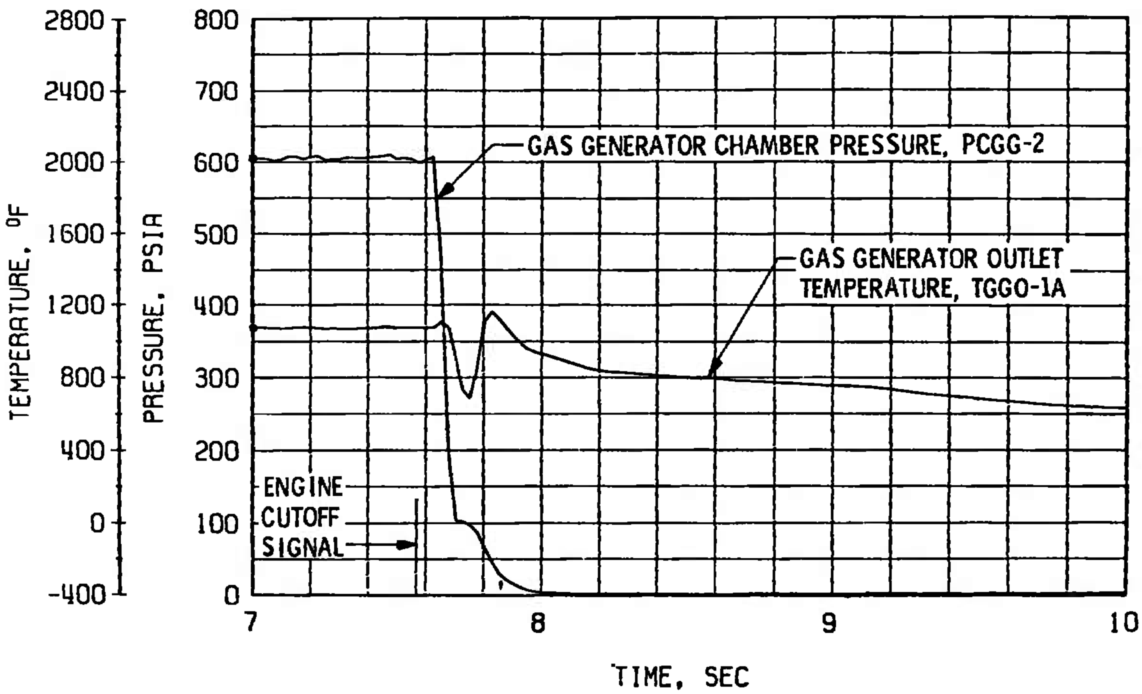


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 27 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 27 Concluded

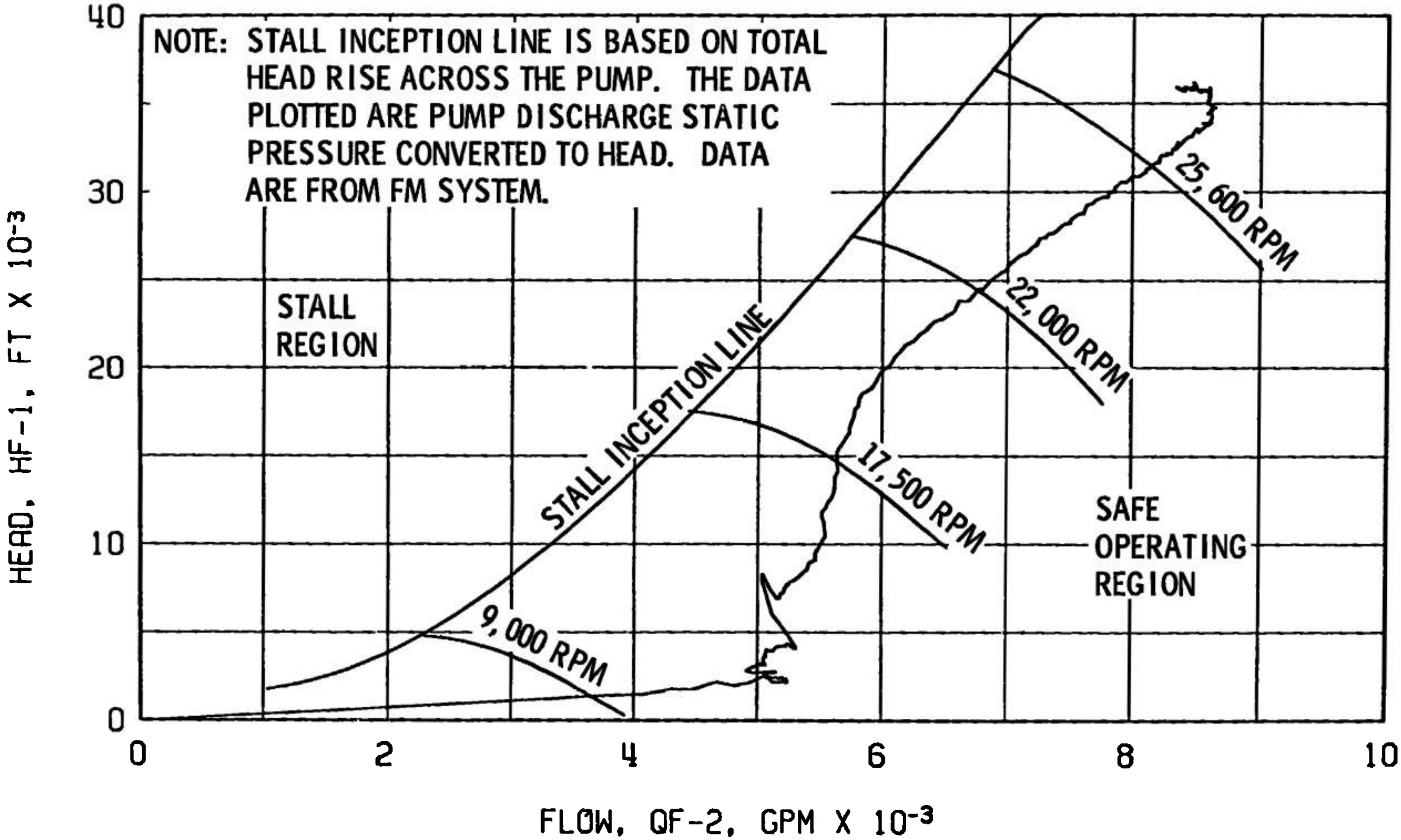
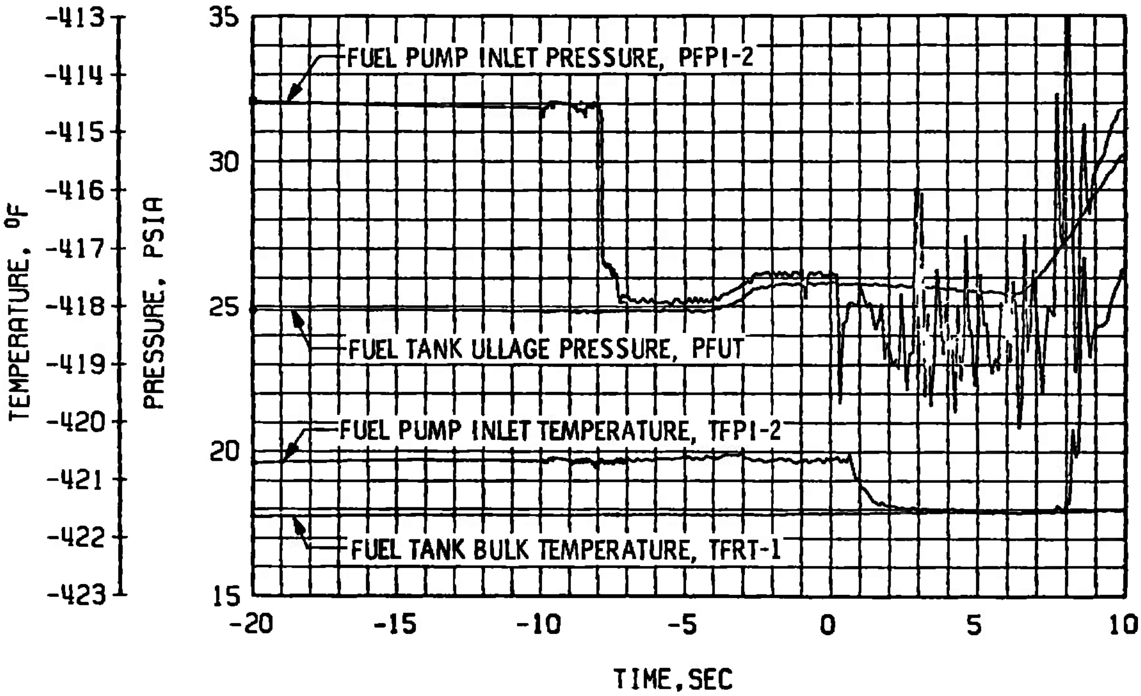
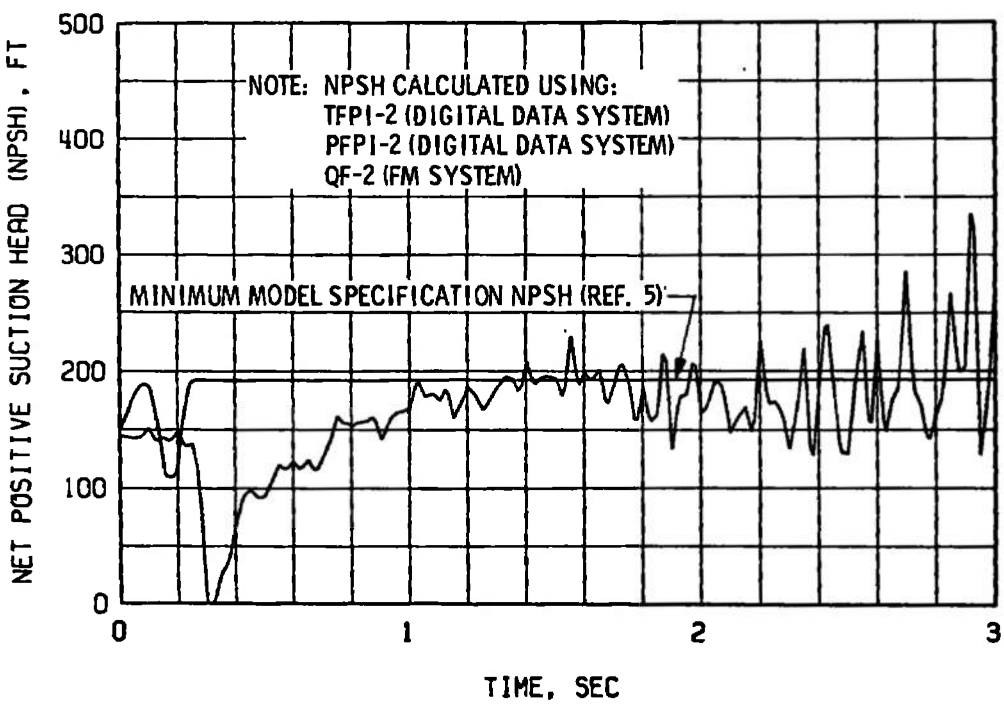


Fig. 28 Fuel Pump Start Transient Performance, Firing 29B

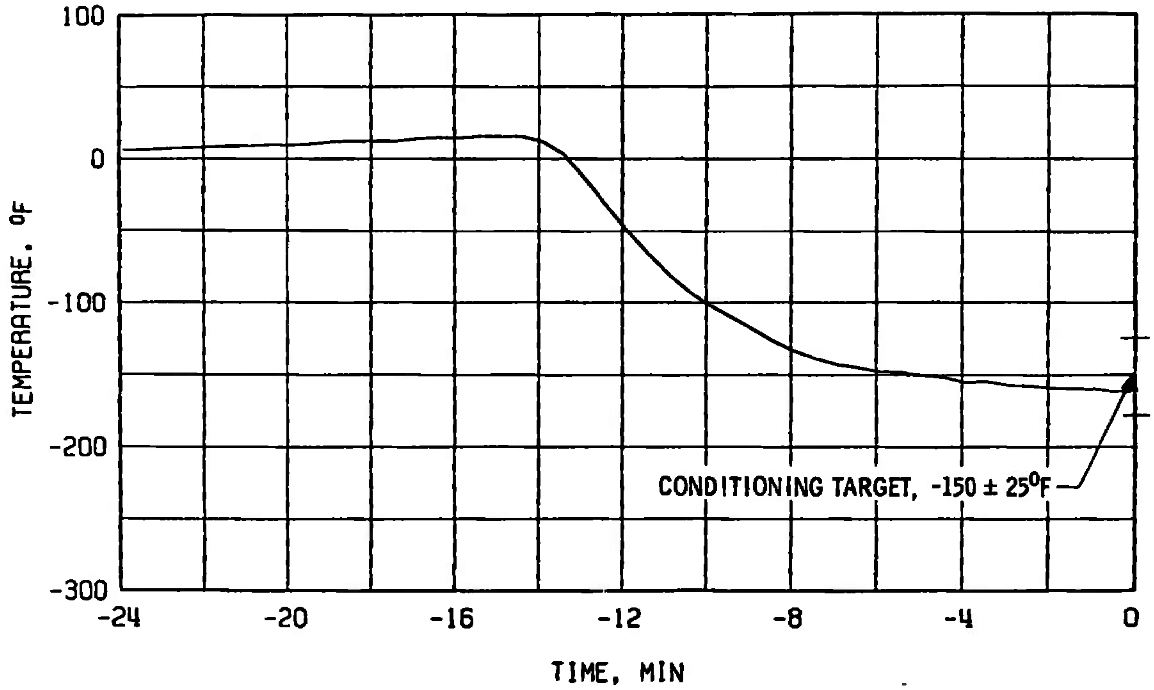


a. Duct Pressure and Temperature Transients

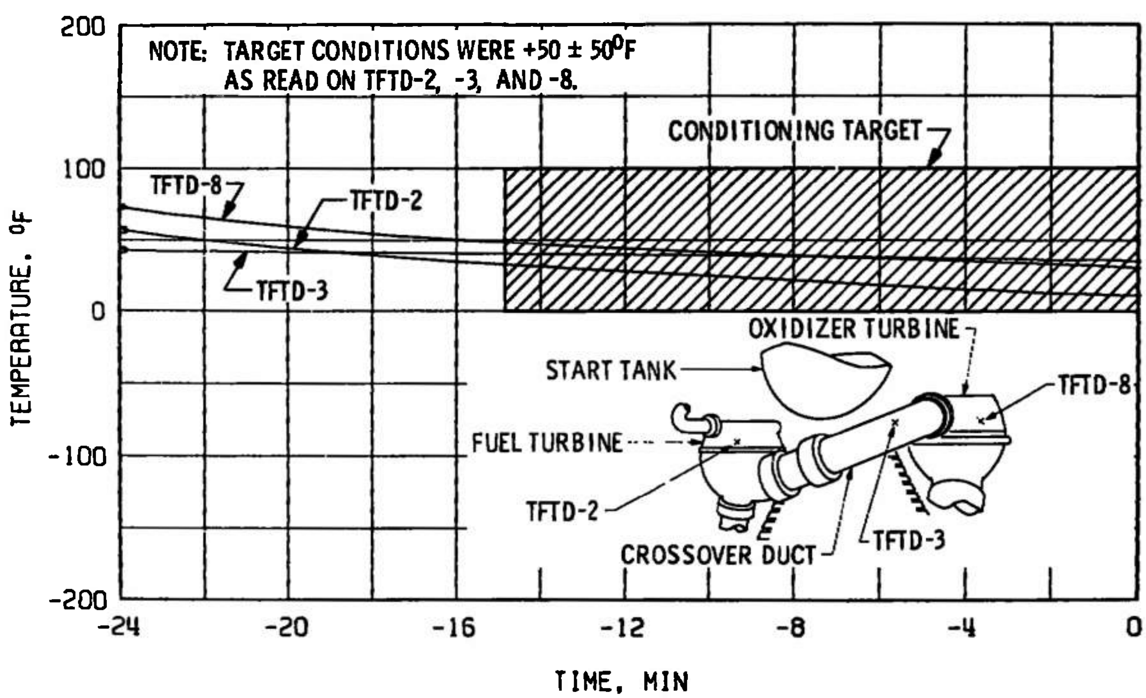


b. Fuel Pump NPSH during Start Transient, Firing 29B

Fig. 29 Fuel Low Pressure Duct Performance, Firing 29B

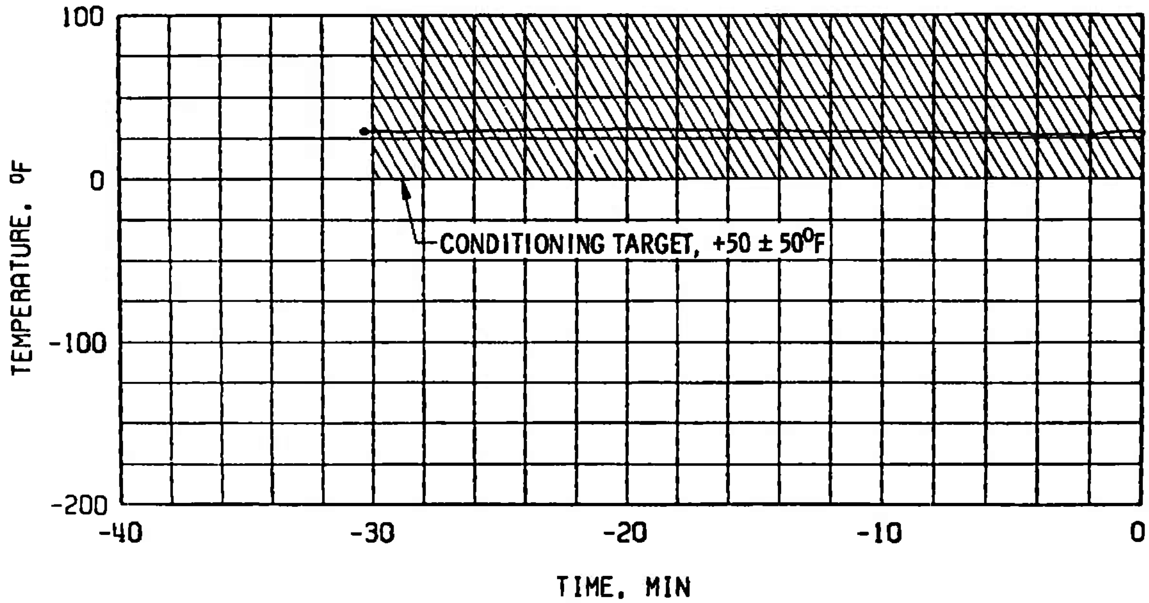


a. Thrust Chamber Throat, TTC-1P

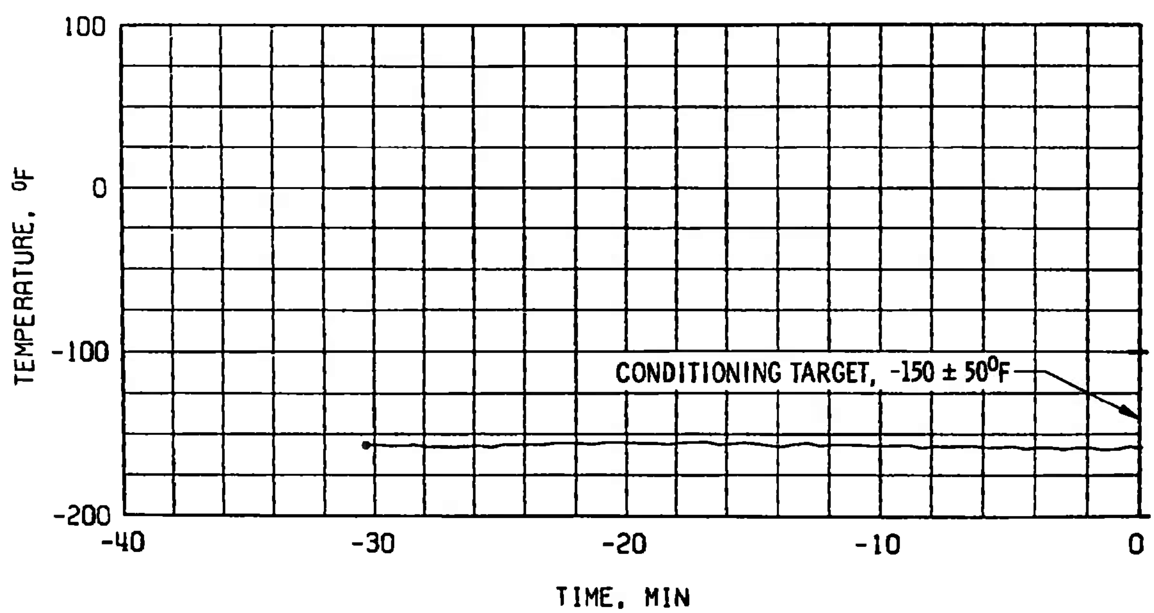


b. Crossover Duct, TFTD

Fig. 30 Thermal Conditioning History of Engine Components, Firing 29C



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 30 Concluded

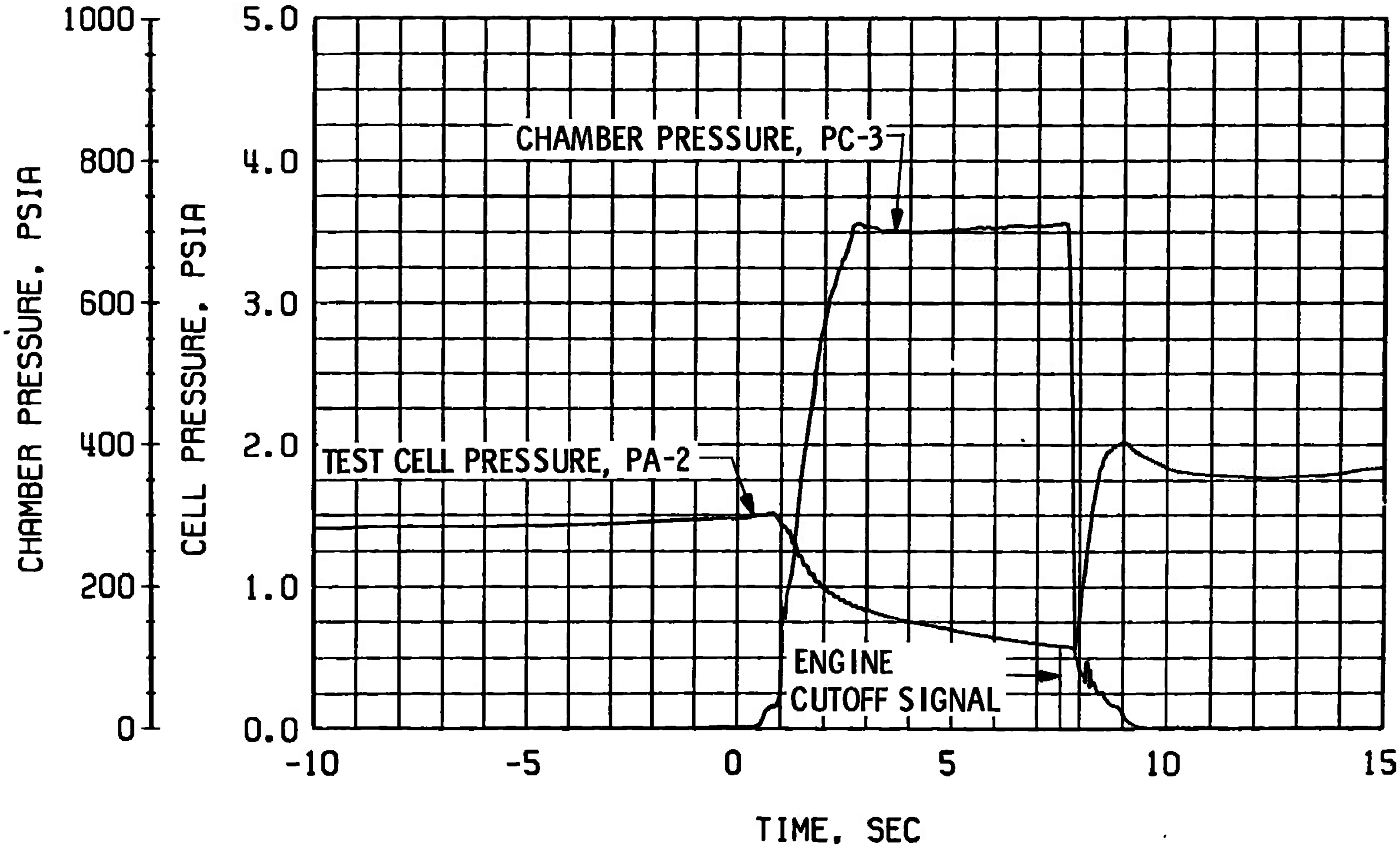
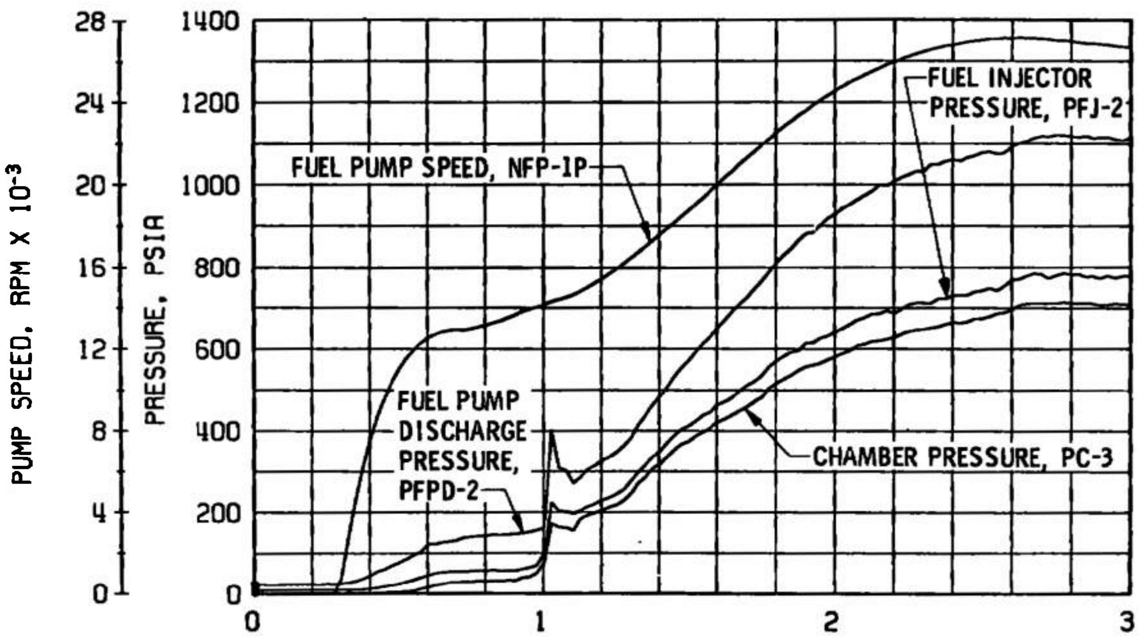
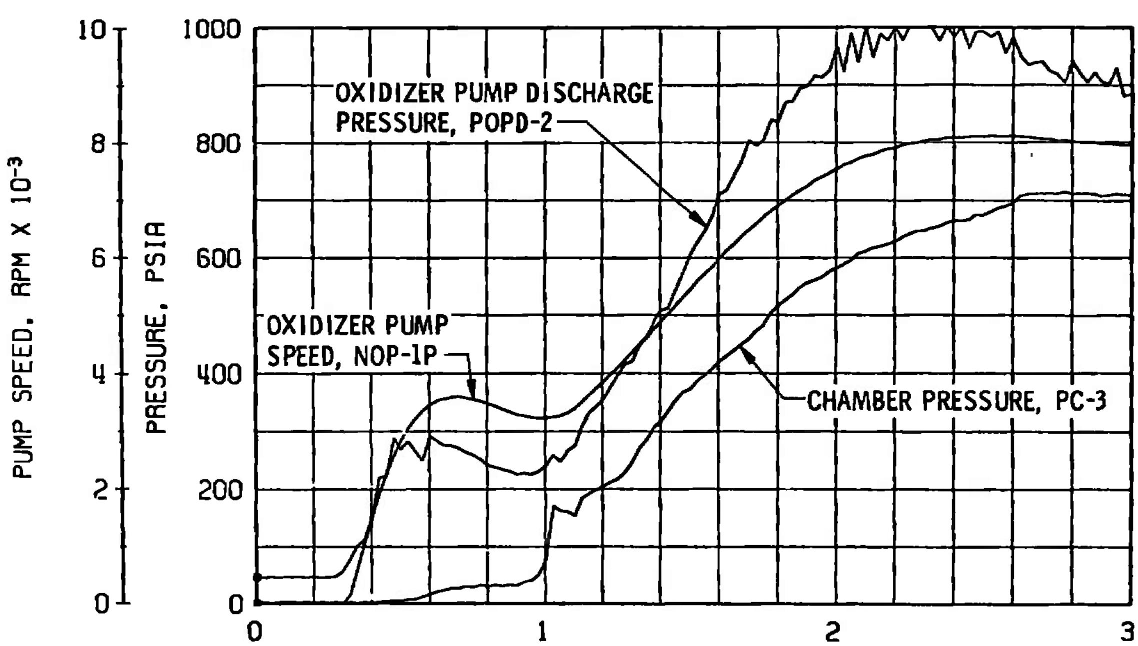


Fig. 31 Engine Ambient and Combustion Chamber Pressures, Firing 29C

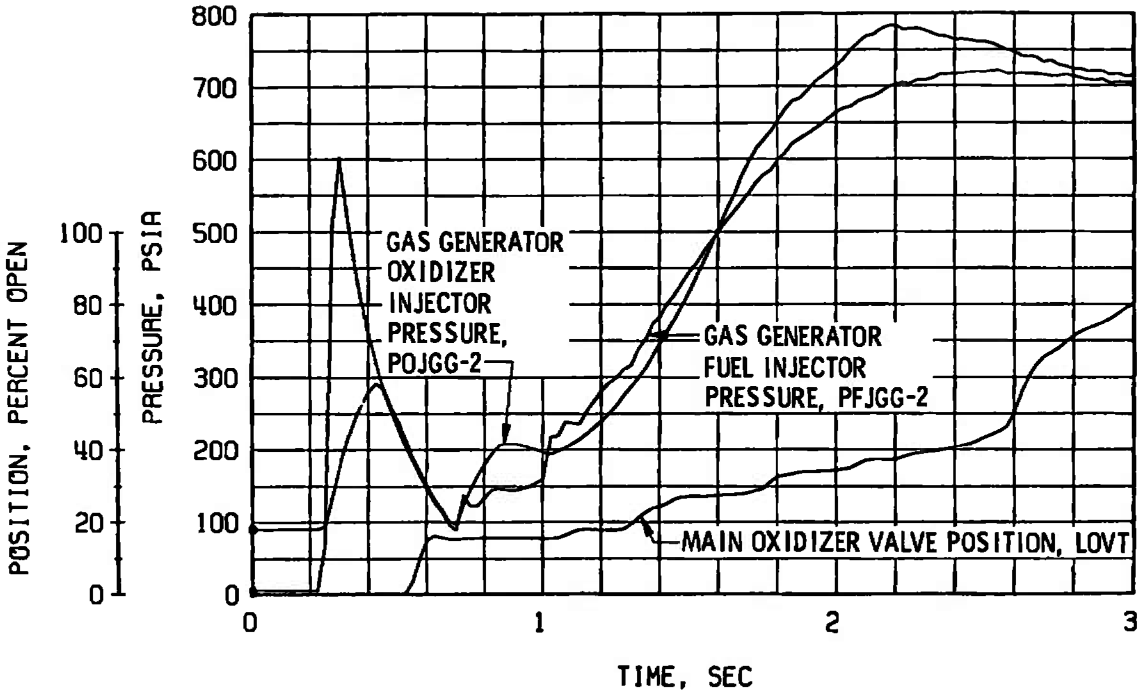


a. Thrust Chamber Fuel System, Start

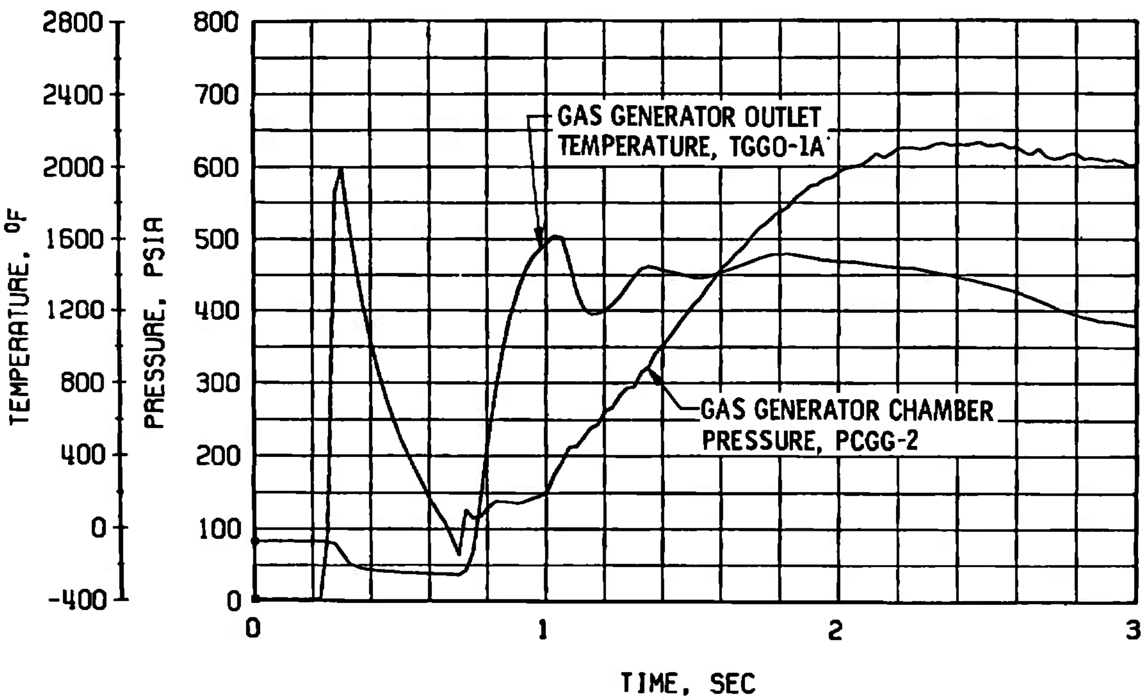


b. Thrust Chamber Oxidizer System, Start

Fig. 32 Engine Transient Operation, Firing 29C

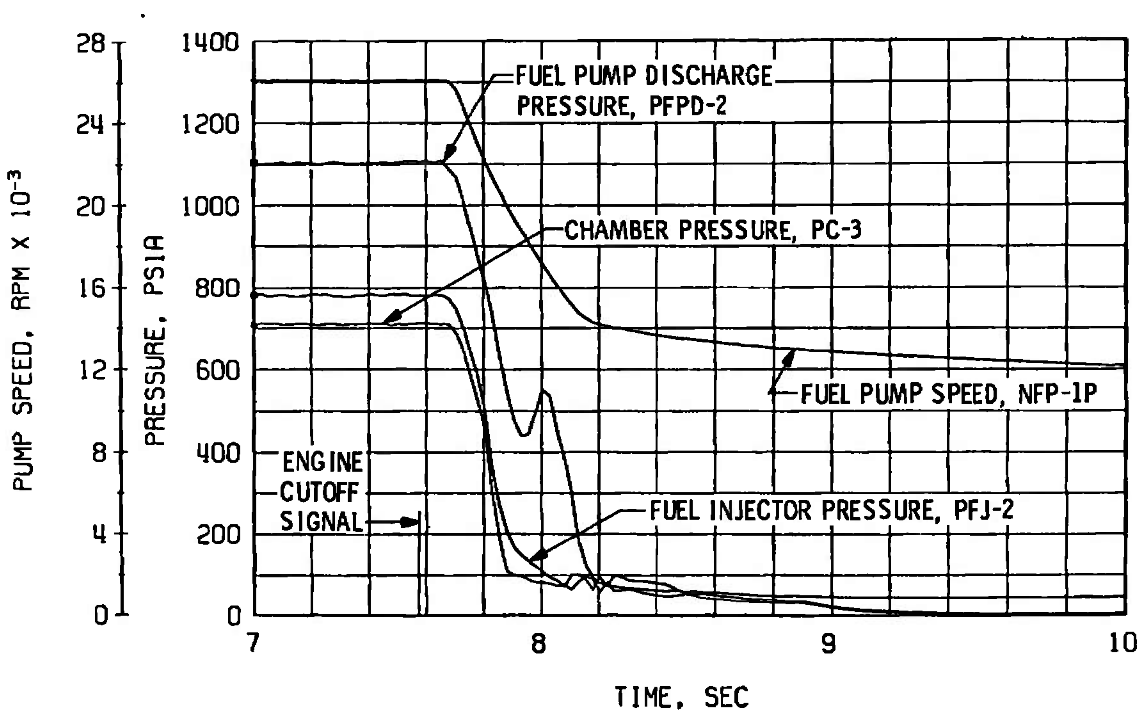


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

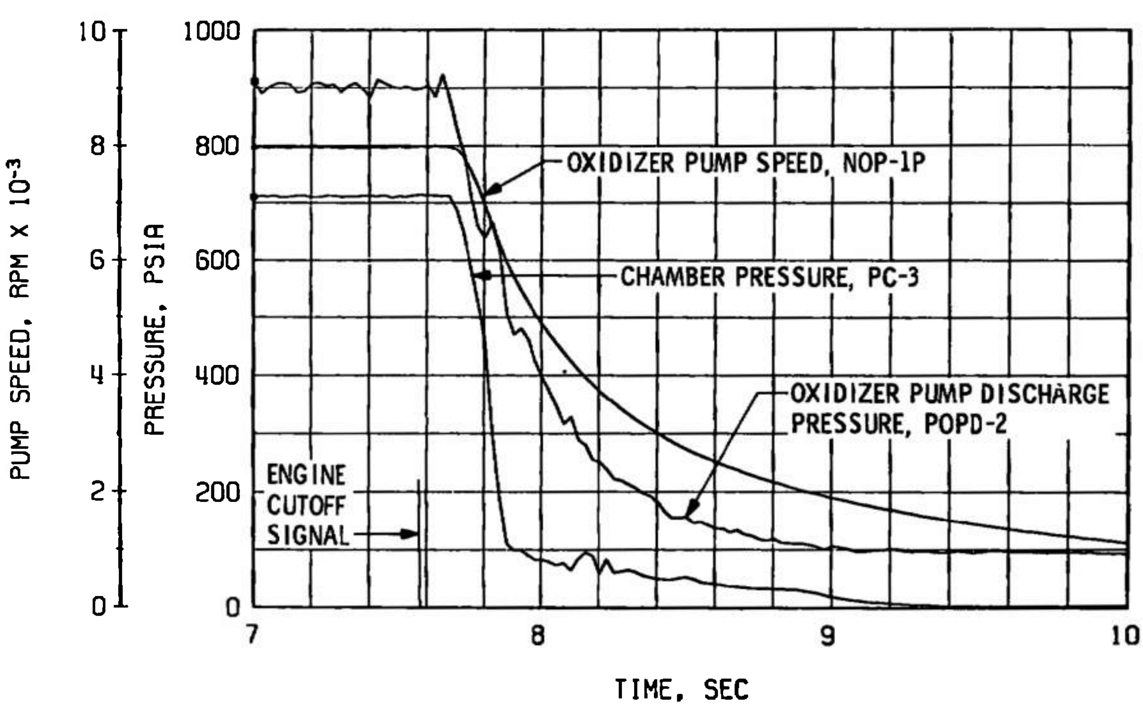


d. Gas Generator Chamber Pressure and Temperature, Start

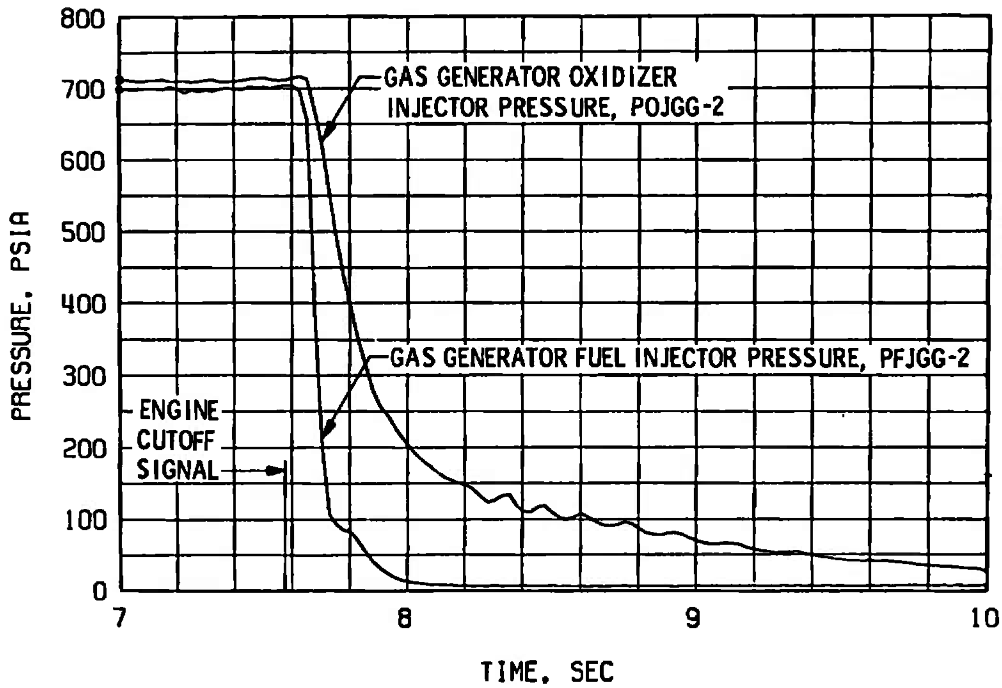
Fig. 32 Continued



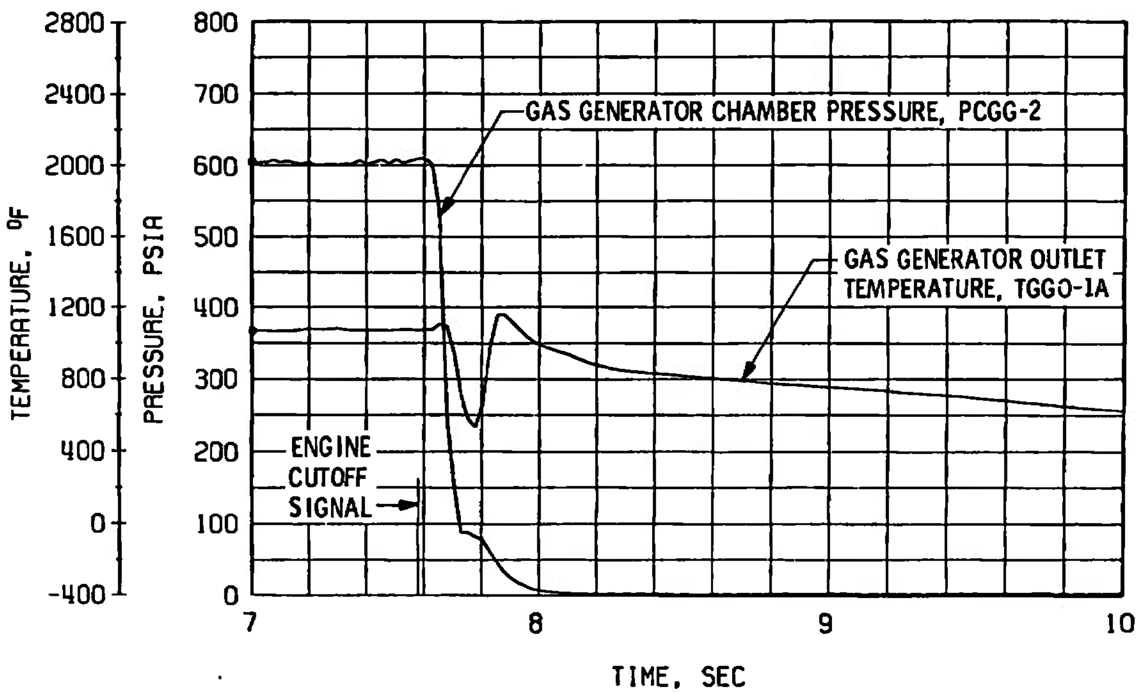
e. Thrust Chamber Fuel System, Shutdown



f. Thrust Chamber Oxidizer System, Shutdown
Fig. 32 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 32 Concluded

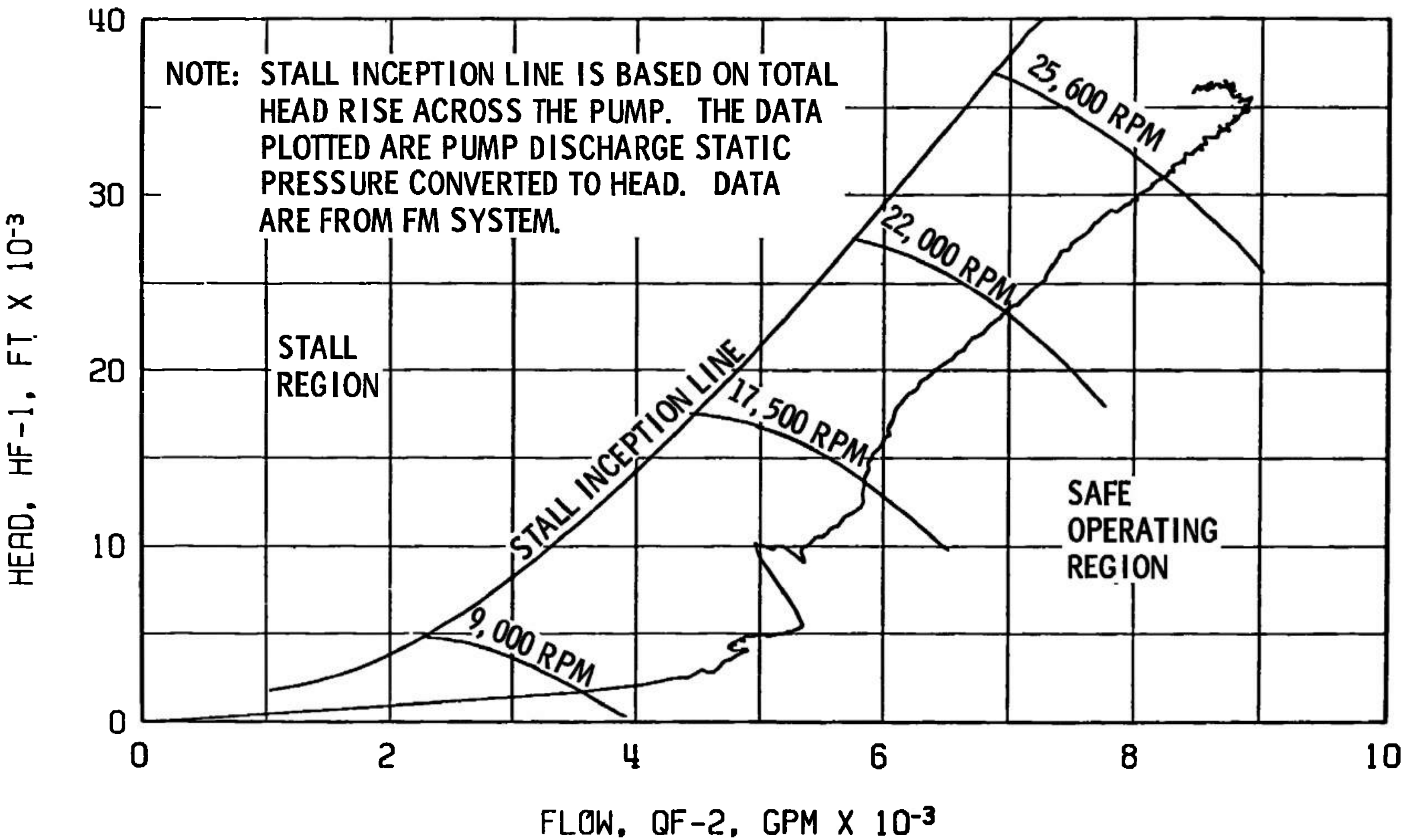
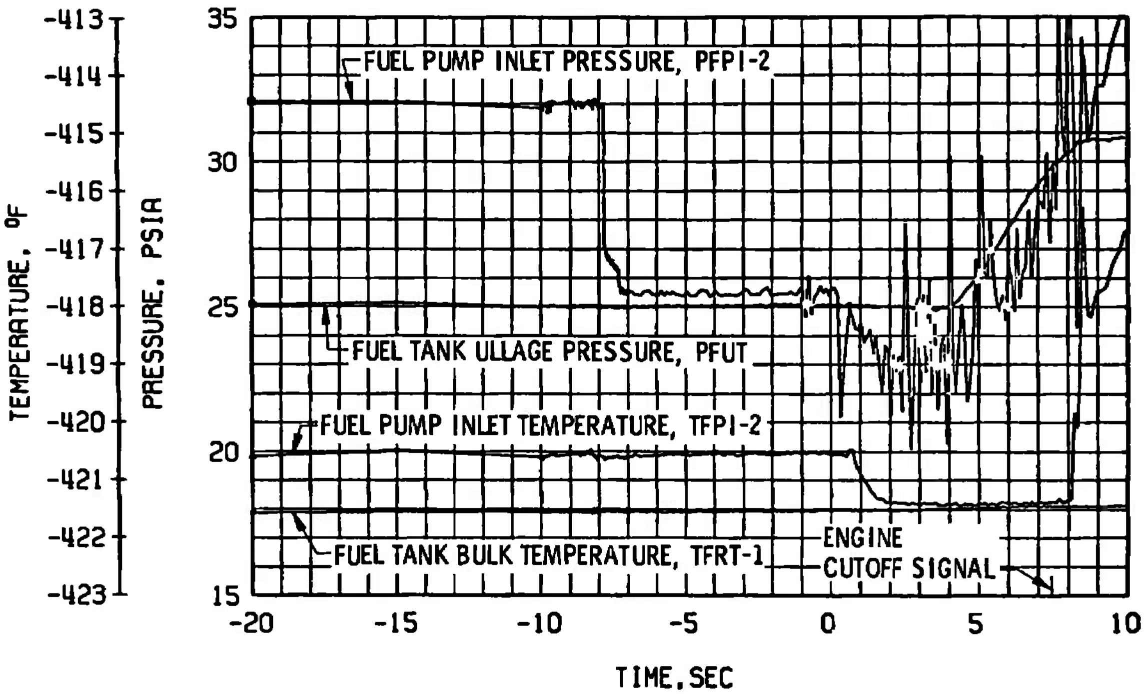
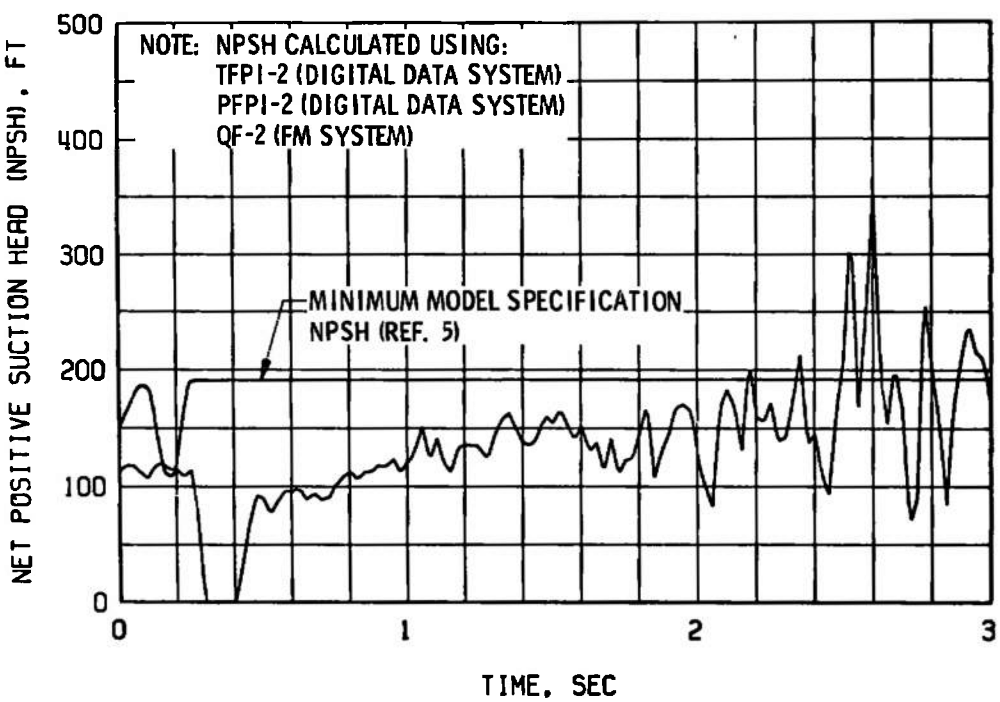


Fig. 33 Fuel Pump Start Transient Performance, Firing 29C

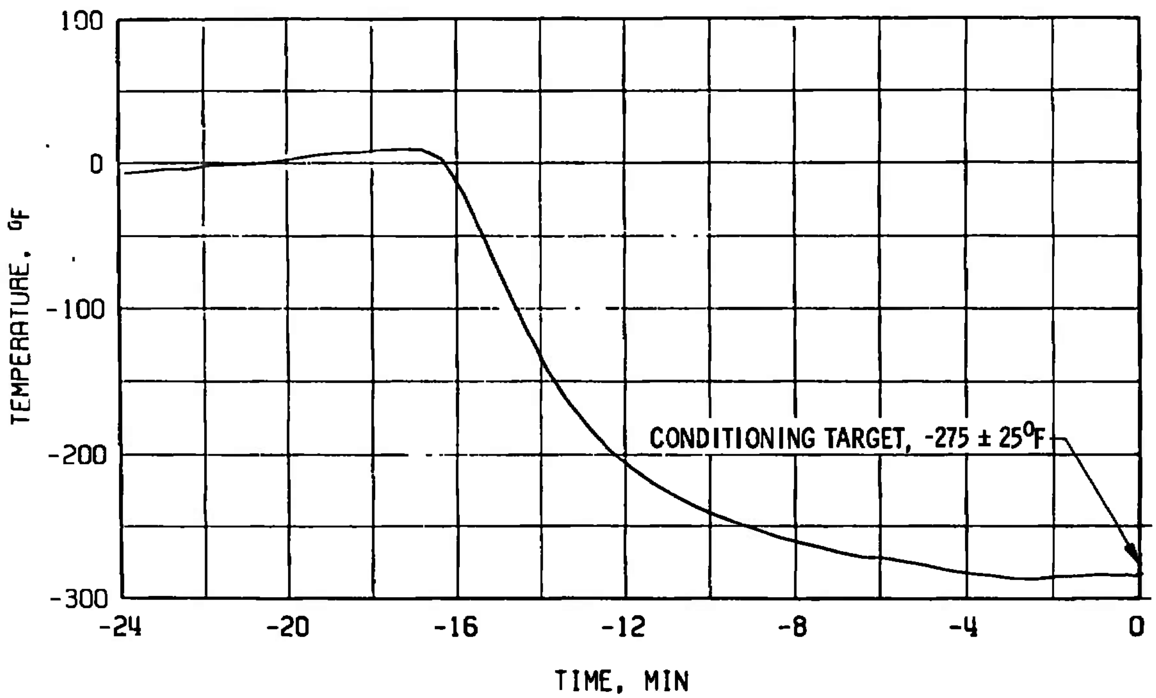


a. Duct Pressure and Temperature Transients

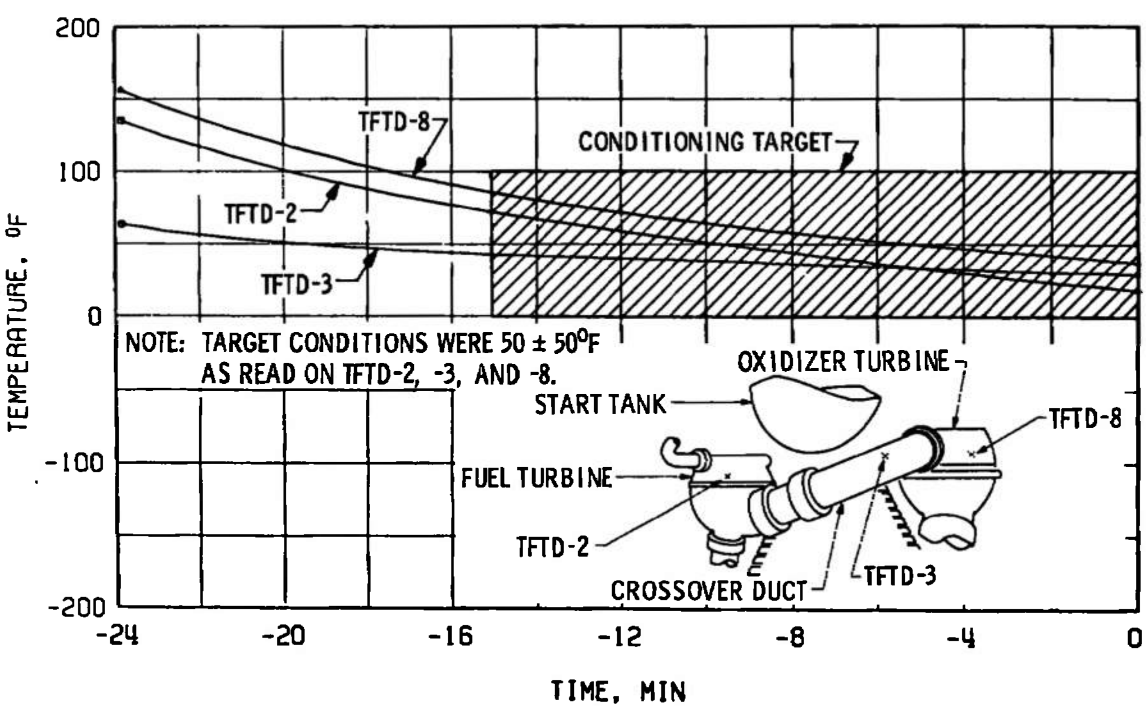


b. Fuel Pump NPSH during Start Transient, Firing 29C

Fig. 34 Fuel Low Pressure Duct Performance, Firing 29C

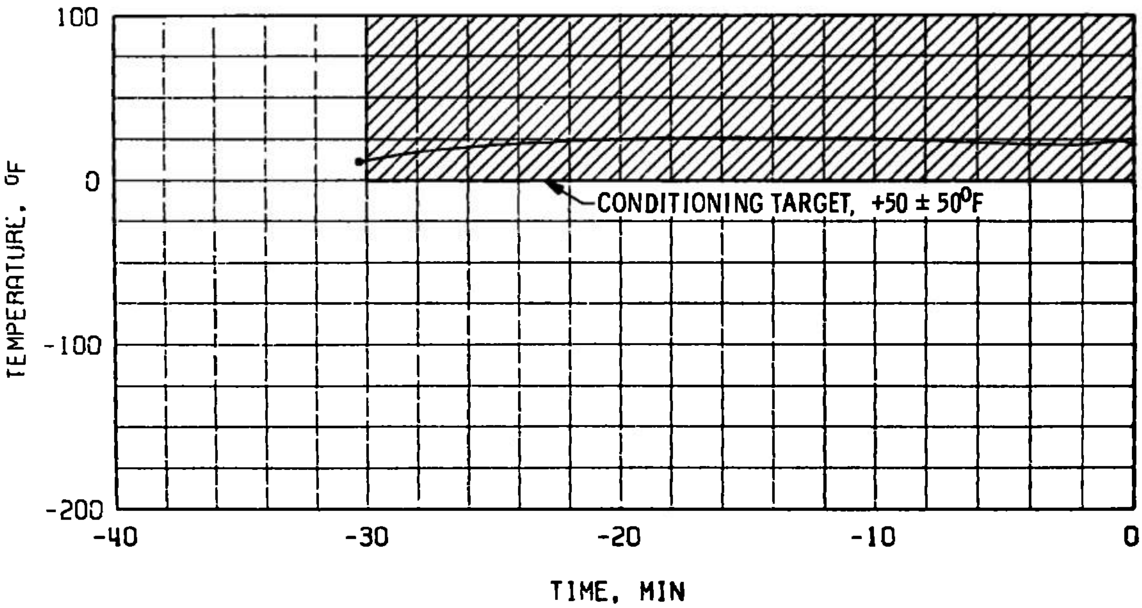


a. Thrust Chamber Throat, TTC-1P

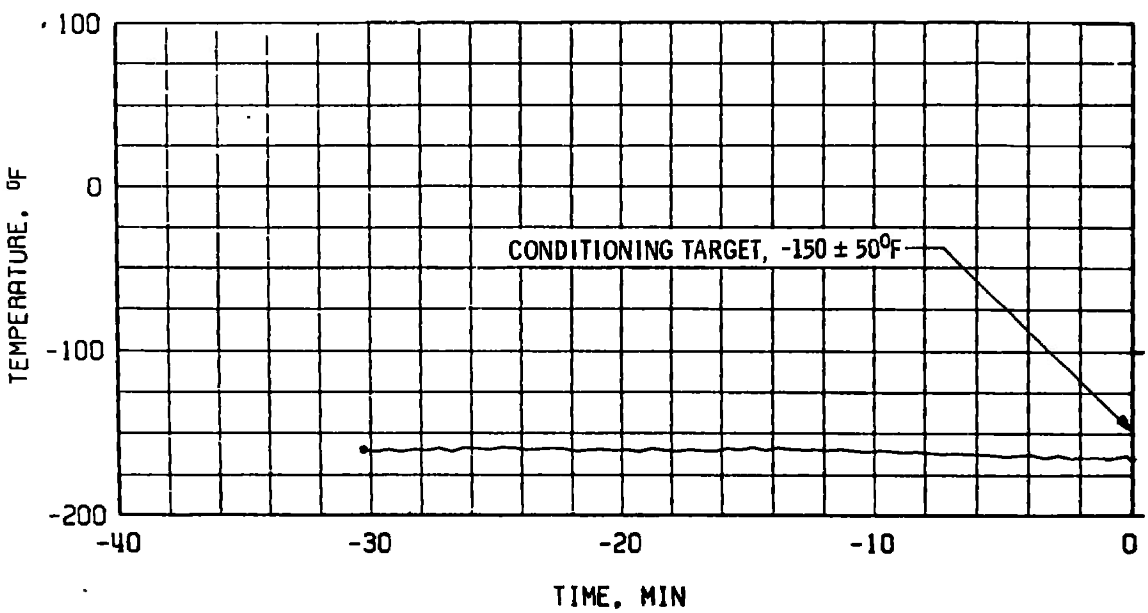


b. Crossover Duct, TFTD

Fig. 35 Thermal Conditioning History of Engine Components, Firing 29D



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 35 Concluded

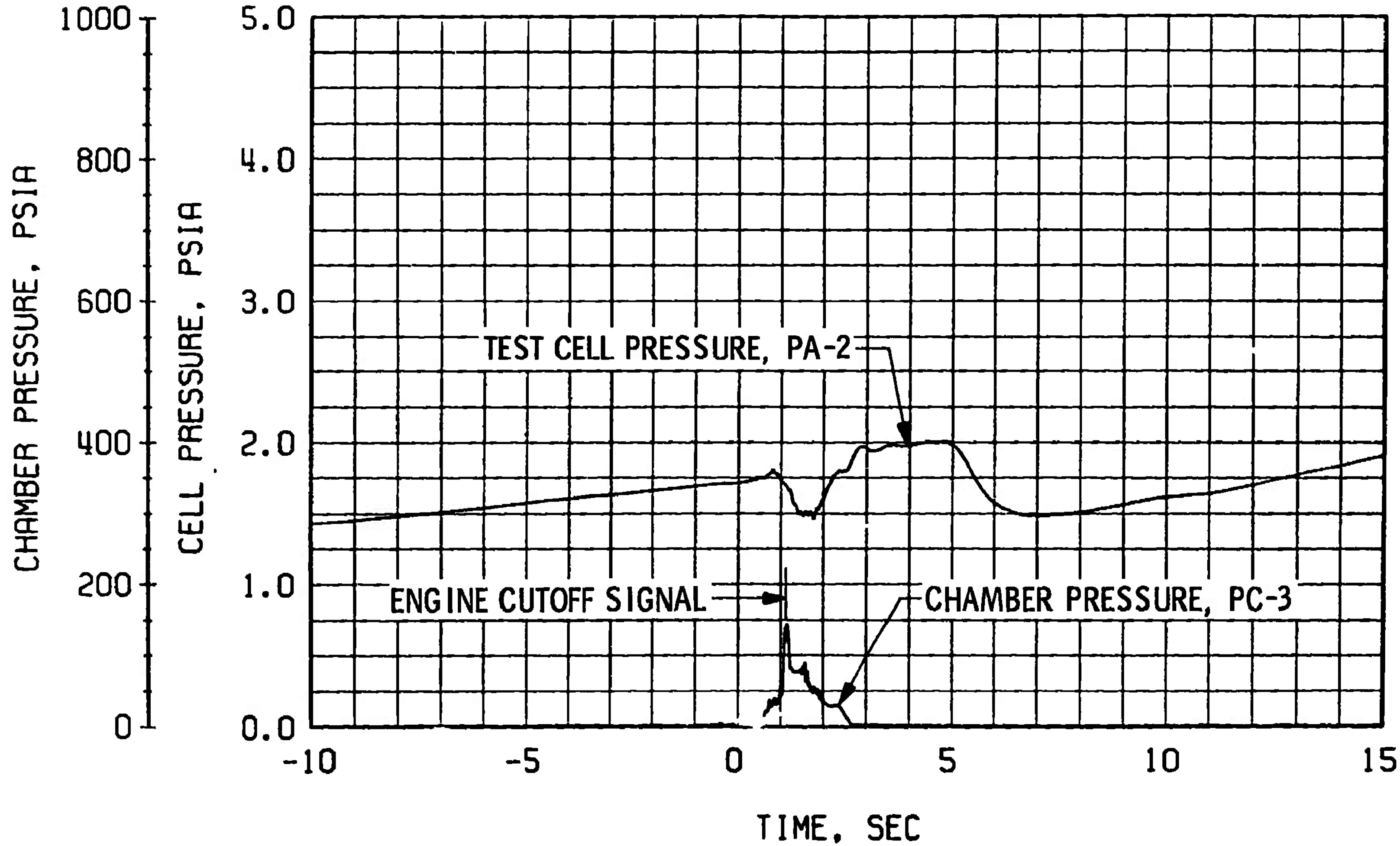
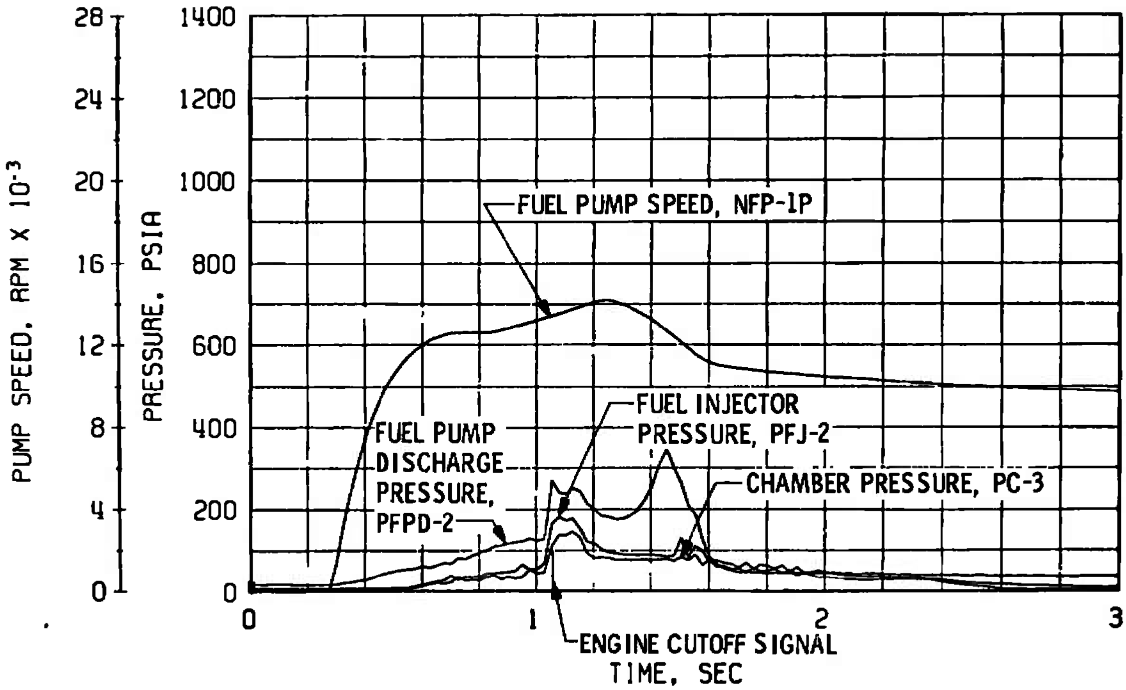
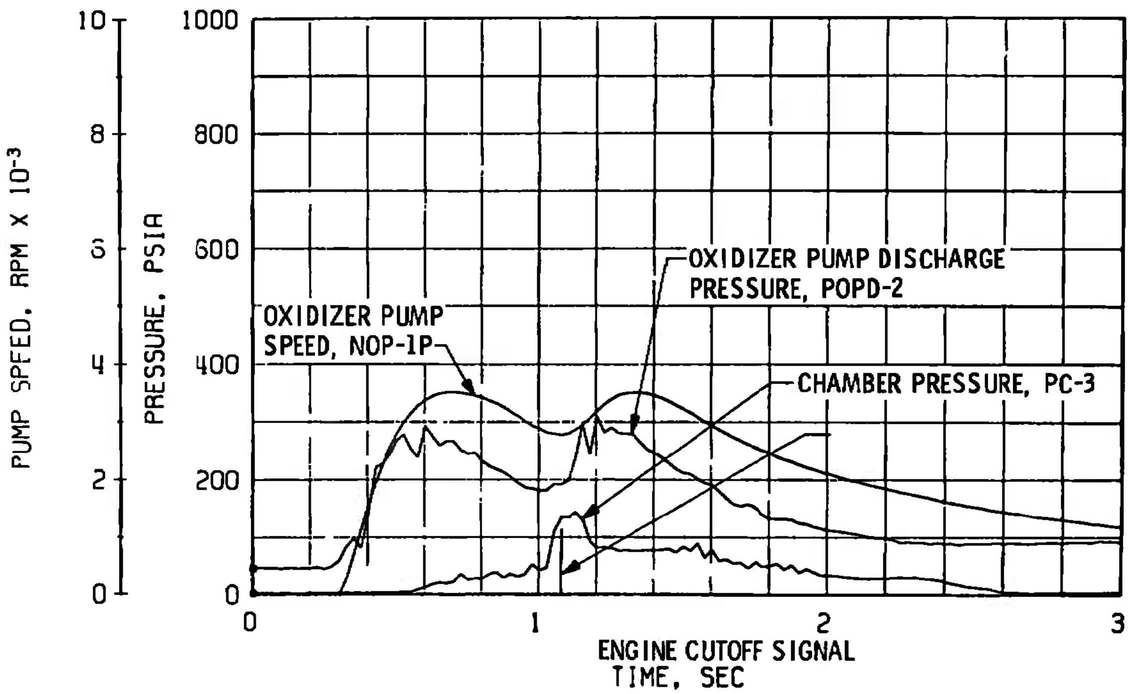


Fig. 36 Engine Ambient and Combustion Chamber Pressures, Firing 29D

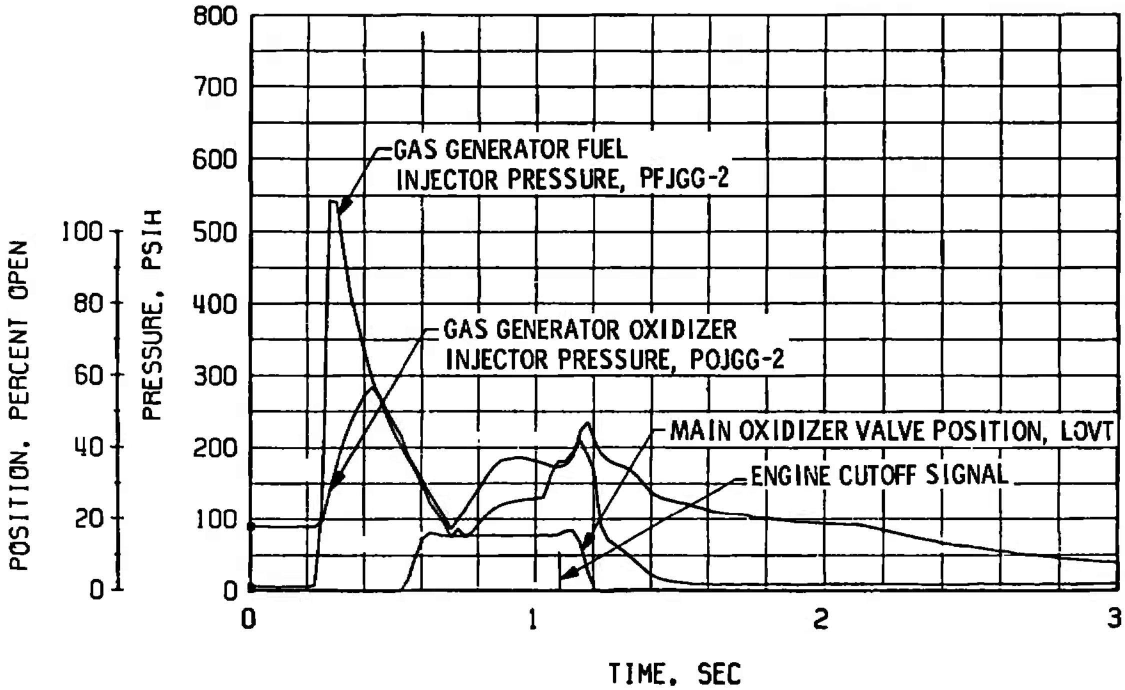


a. Thrust Chamber Fuel System, Start and Shutdown

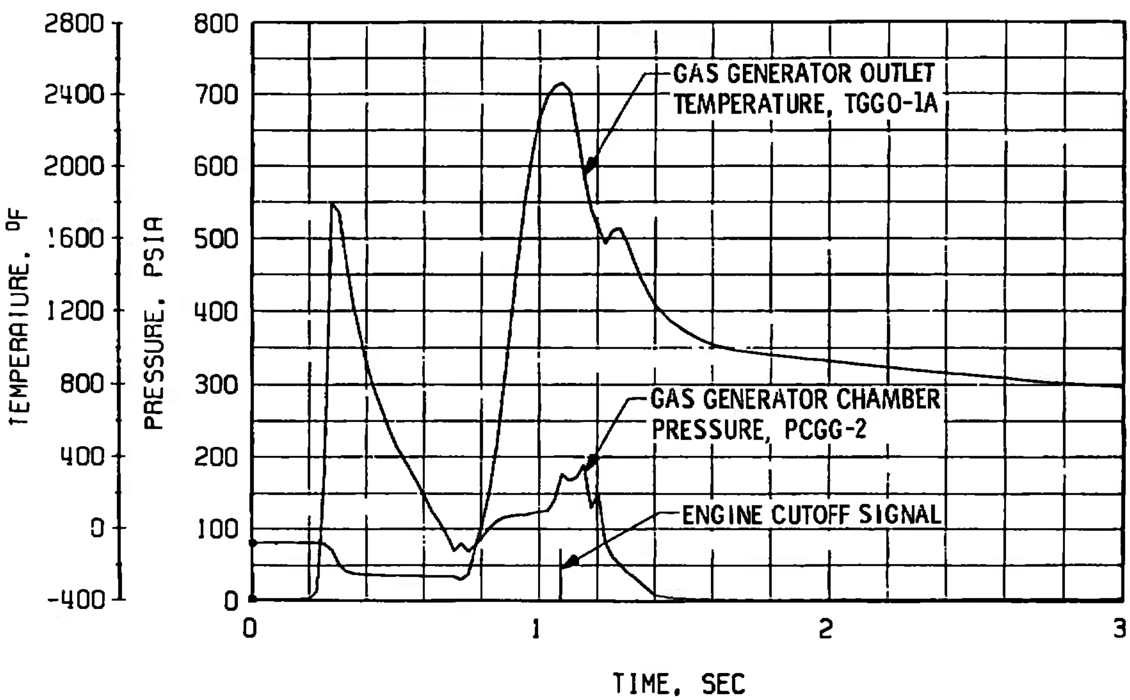


b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 37 Engine Transient Operation, Firing 29D



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 37 Concluded

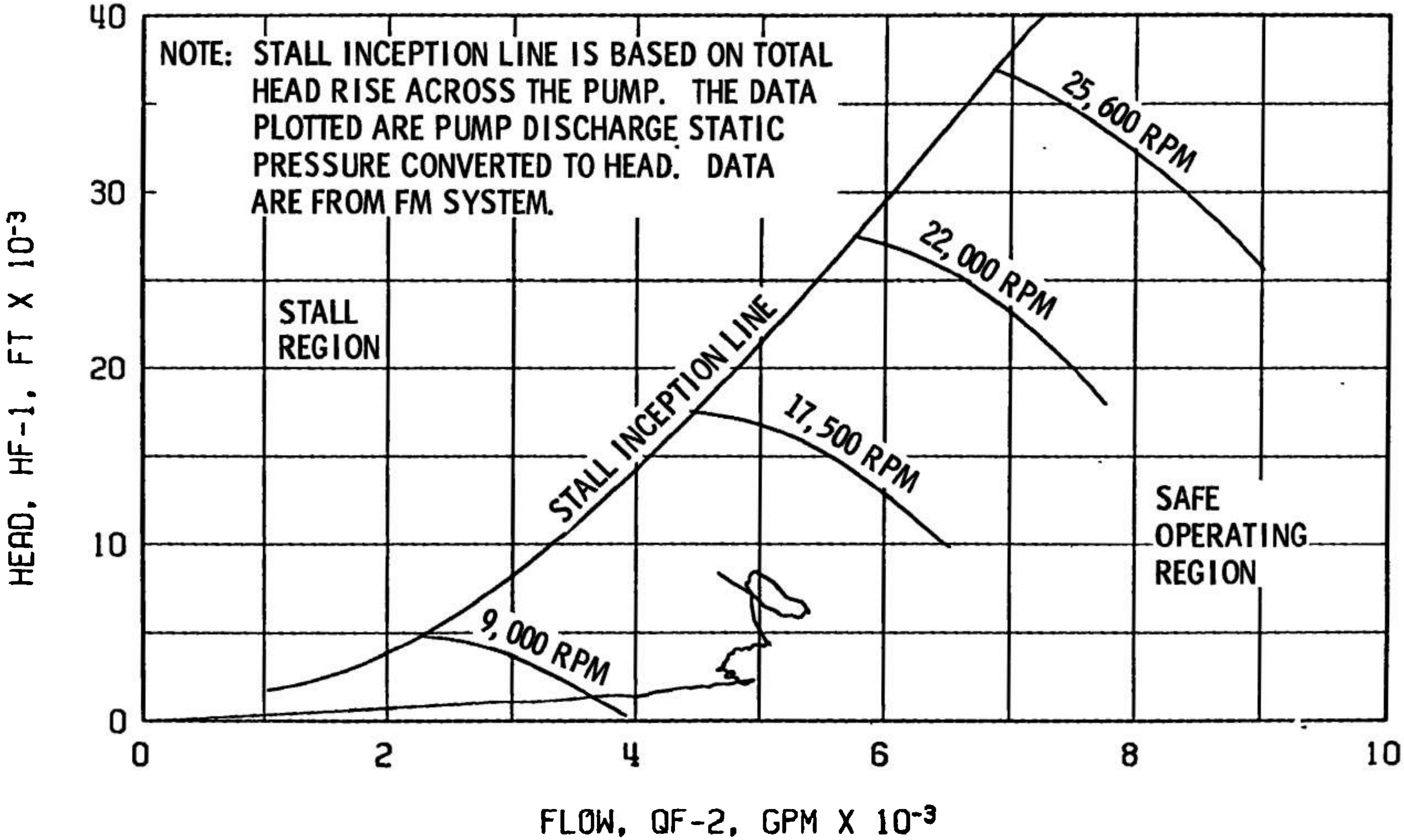
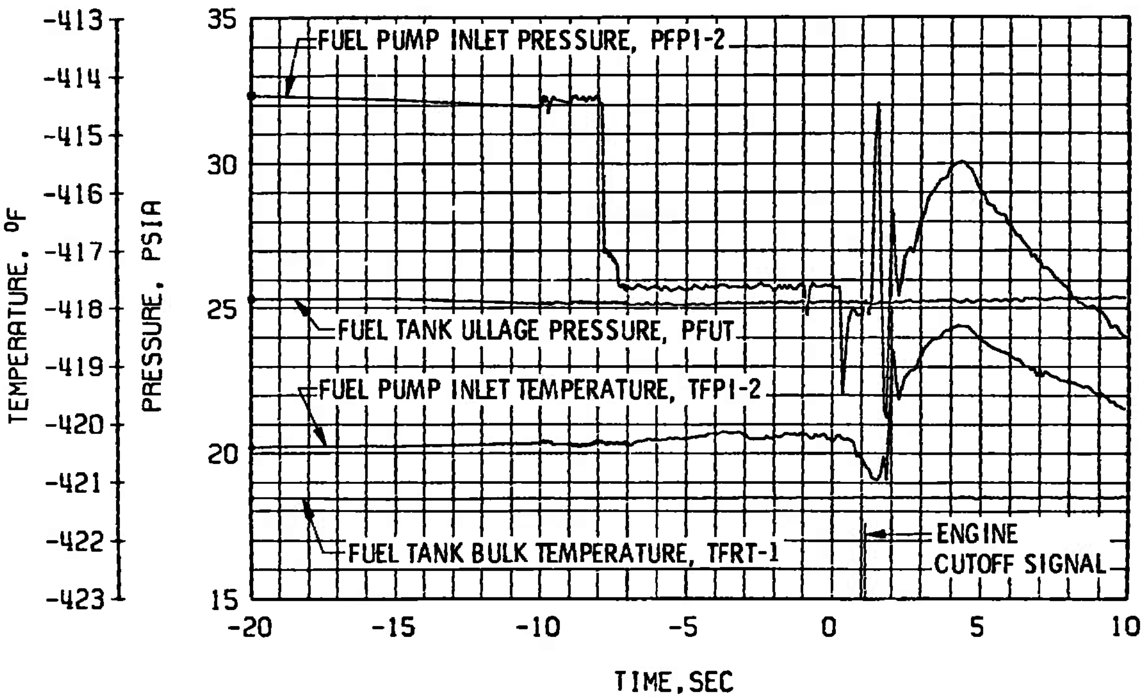
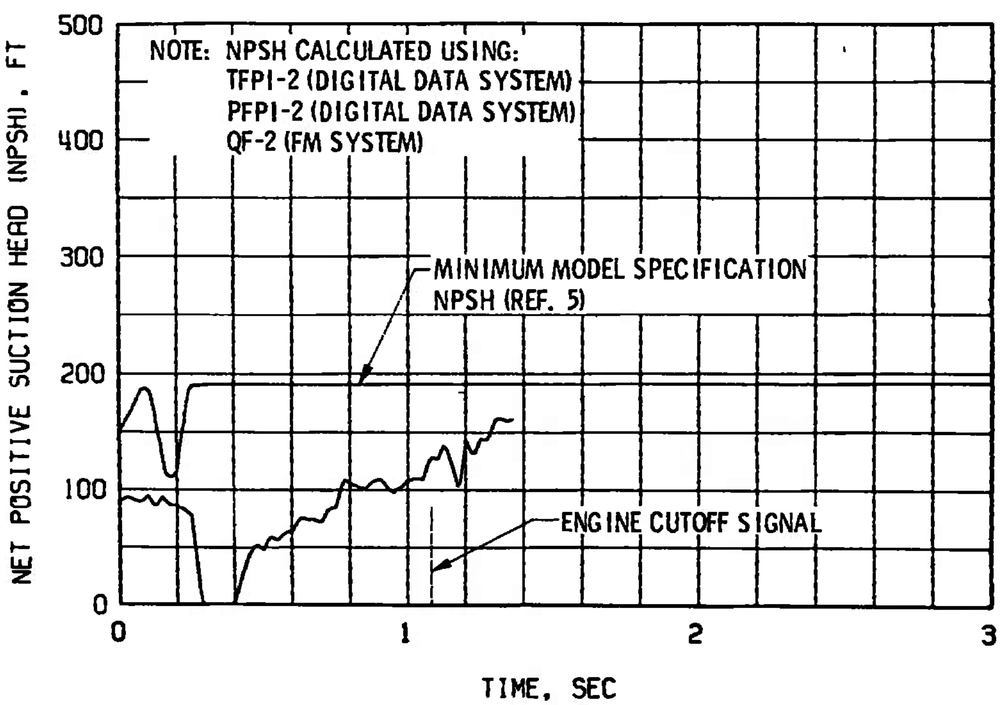


Fig. 38 Fuel Pump Start Transient Performance, Firing 29D

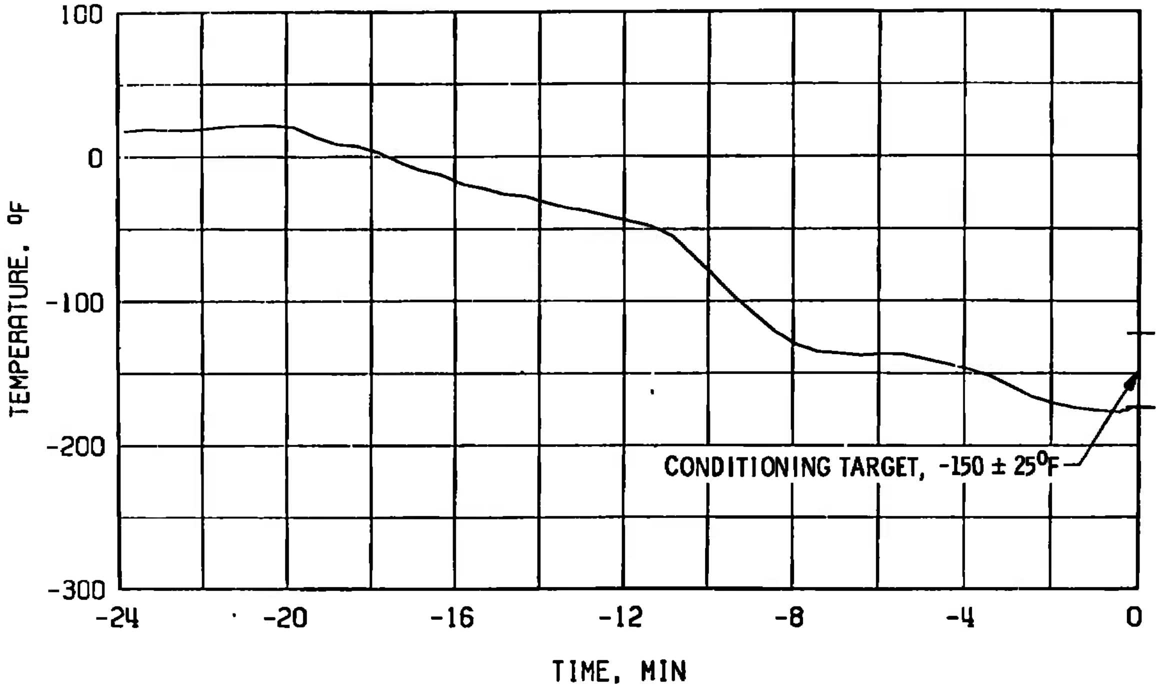


a. Duct Pressure and Temperature Transients

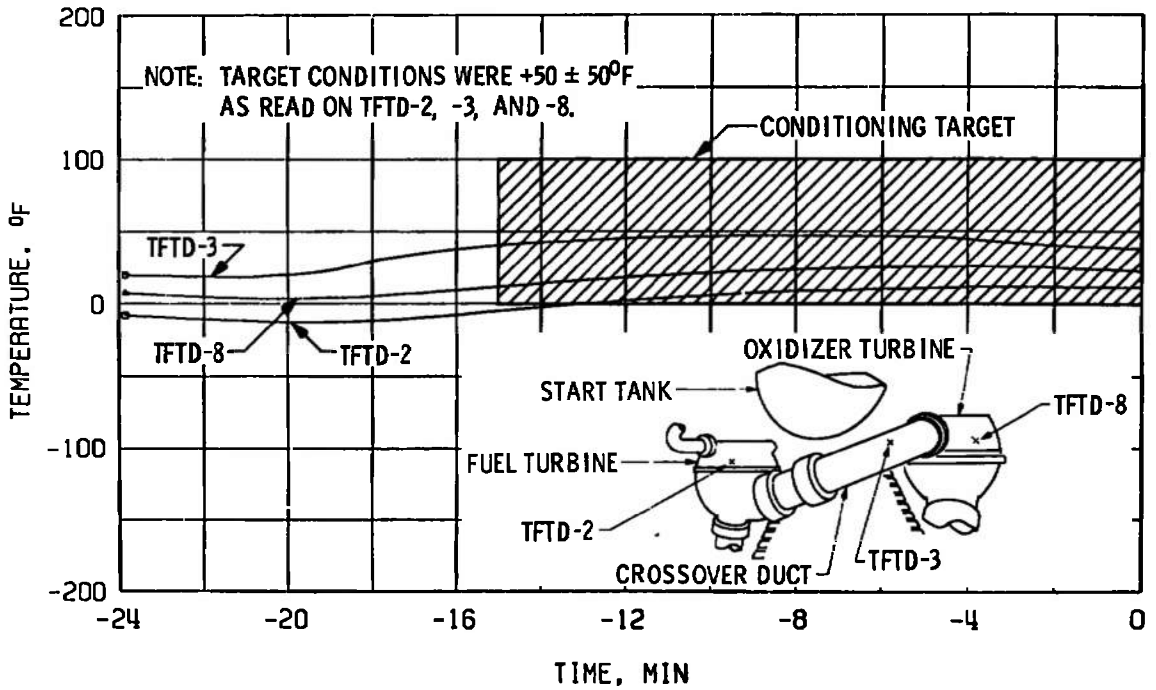


b. Fuel Pump NPSH during Start Transient, Firing 29D

Fig. 39 Fuel Low Pressure Duct Performance, Firing 29D

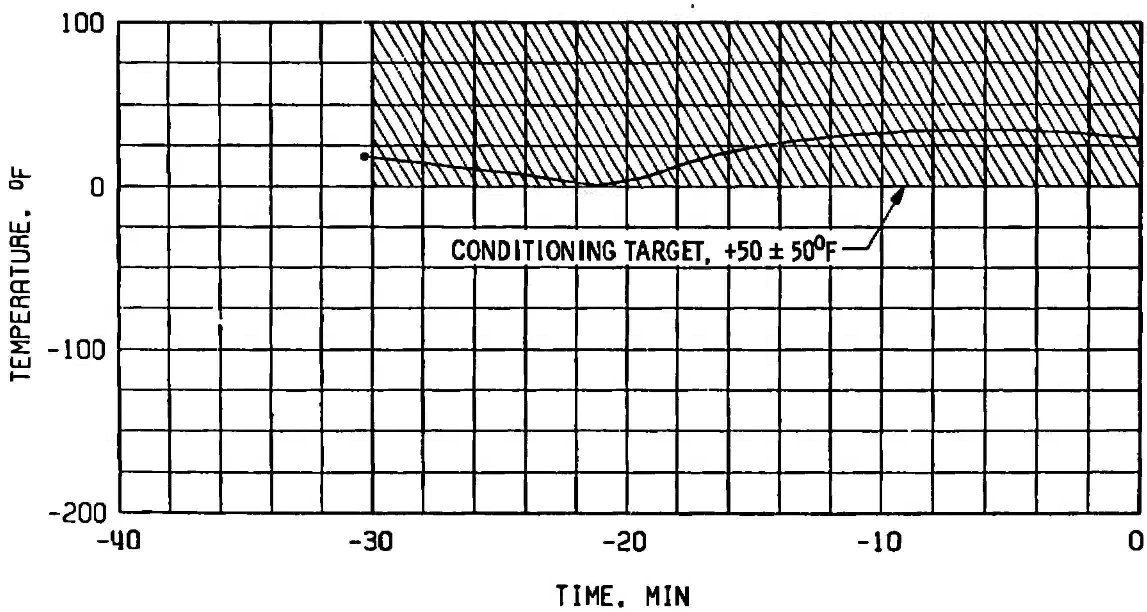


a. Thrust Chamber Throat, TTC-1P

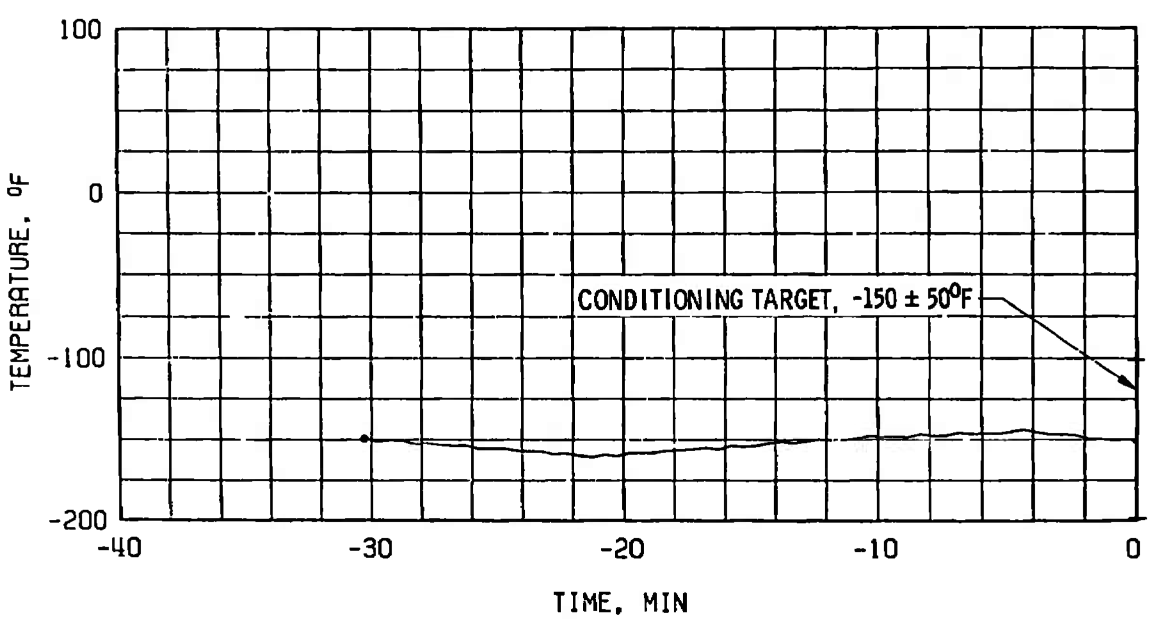


b. Crossover Duct, TFTD

Fig. 40 Thermal Conditioning History of Engine Components, Firing 29E



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 40 Concluded

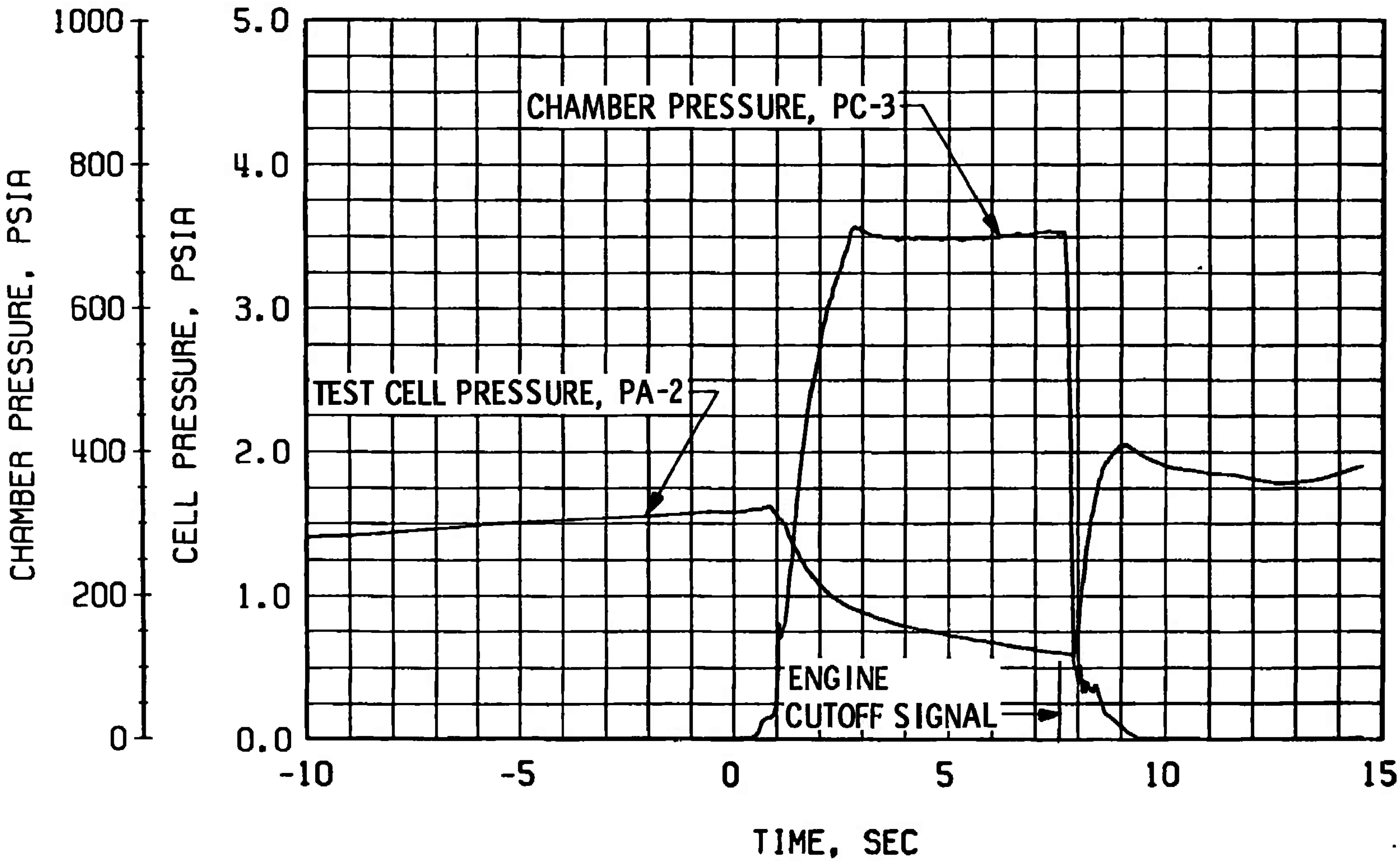
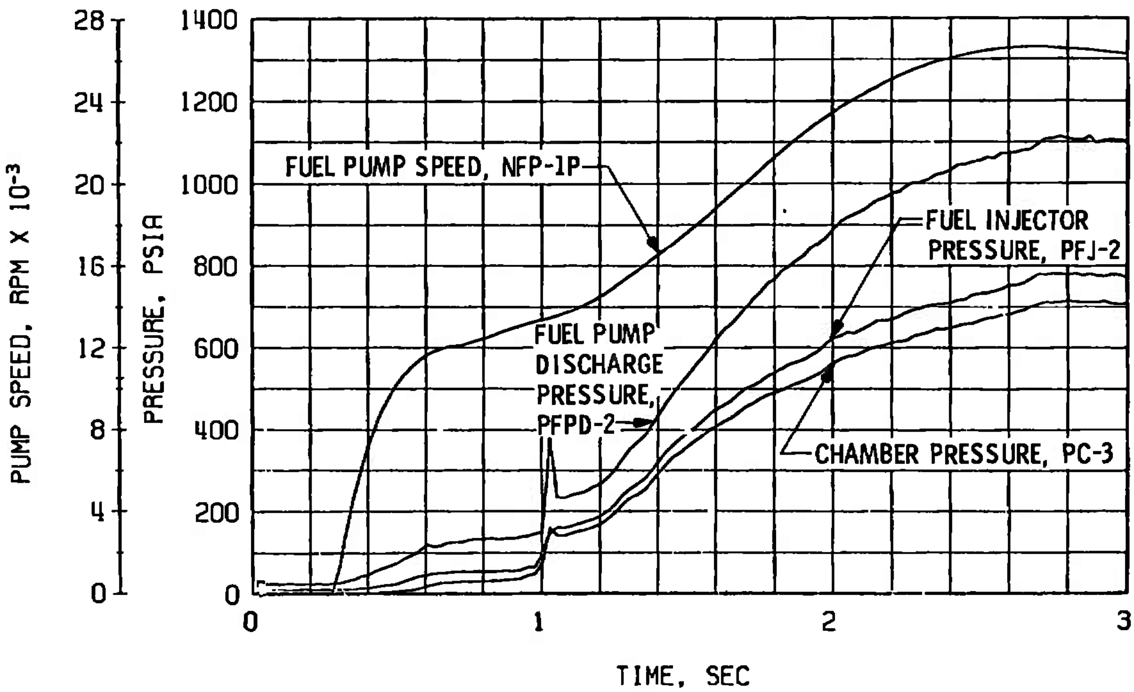
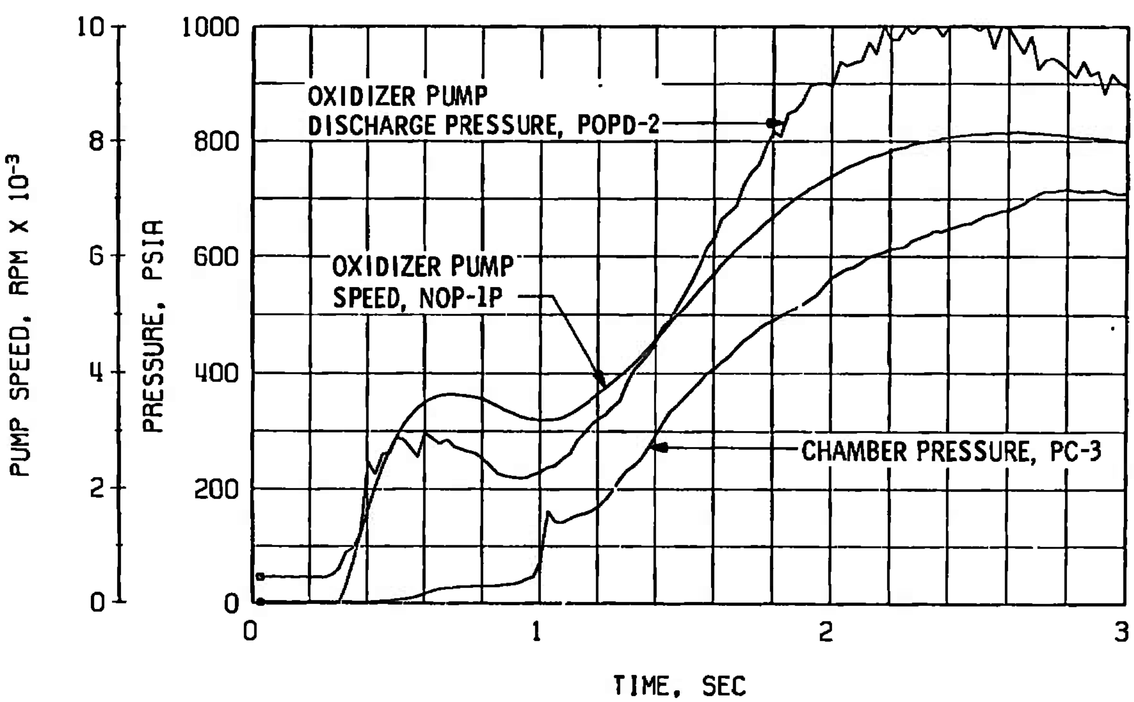


Fig. 41 Engine Ambient and Combustion Chamber Pressures, Firing 29E

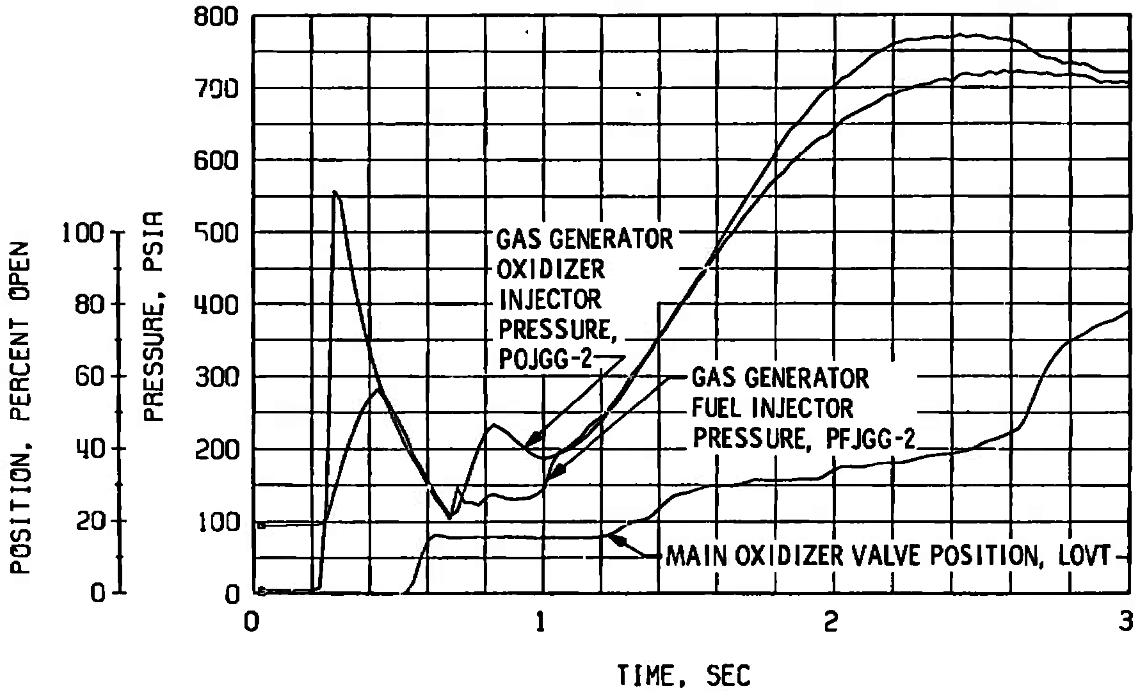


a. Thrust Chamber Fuel System, Start

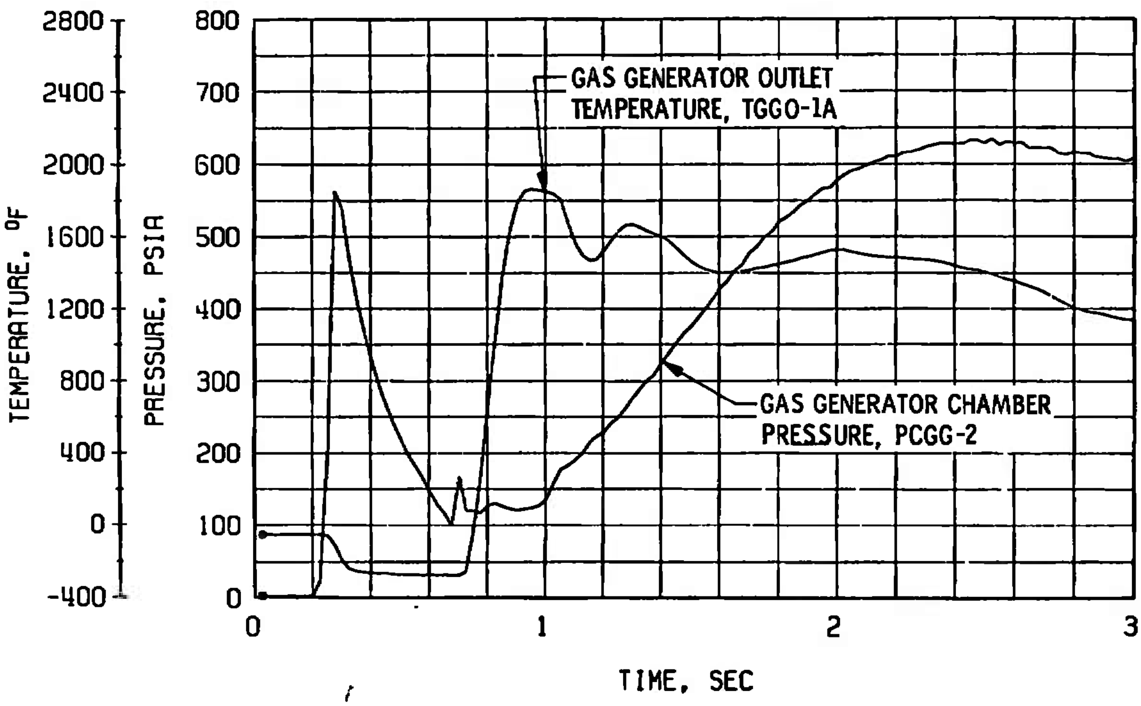


b. Thrust Chamber Oxidizer System, Start

Fig. 42 Engine Transient Operation, Firing 29E

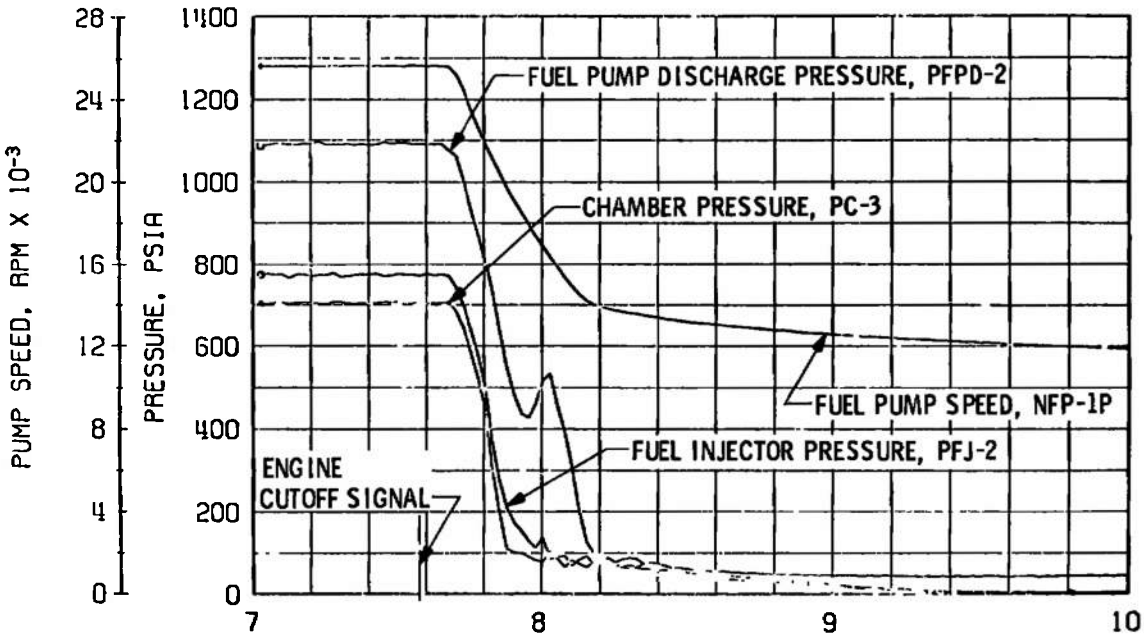


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

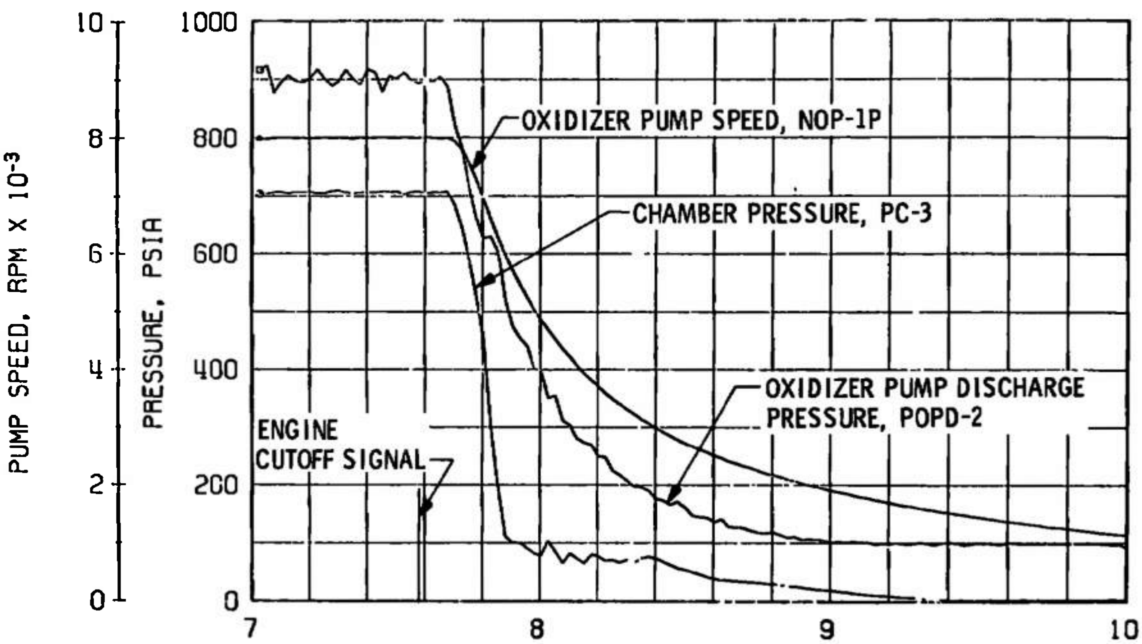


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 42 Continued

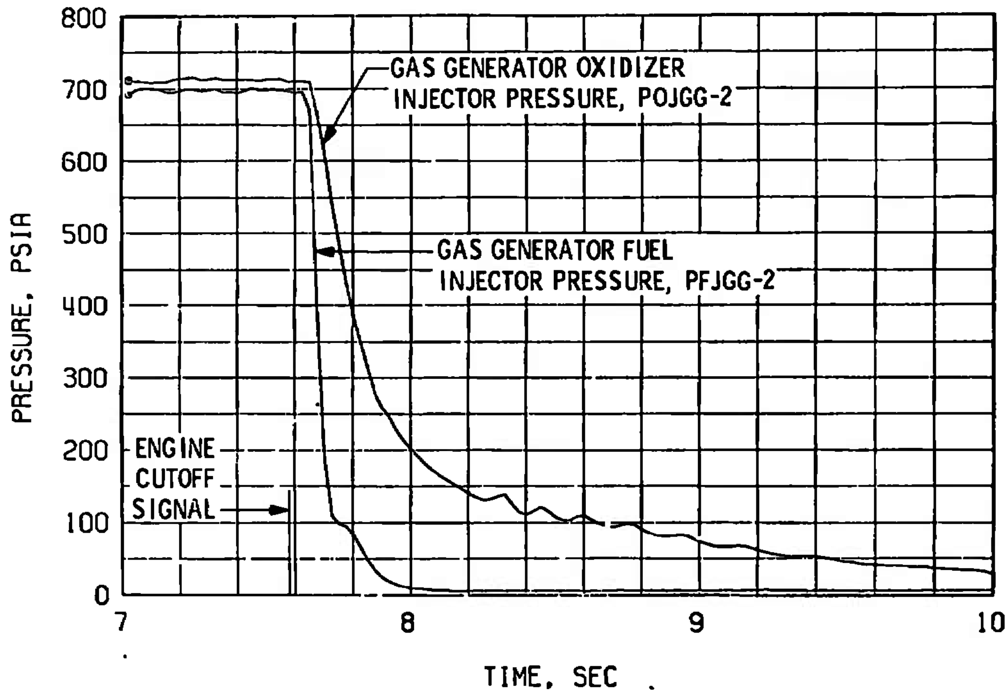


e. Thrust Chamber Fuel System, Shutdown

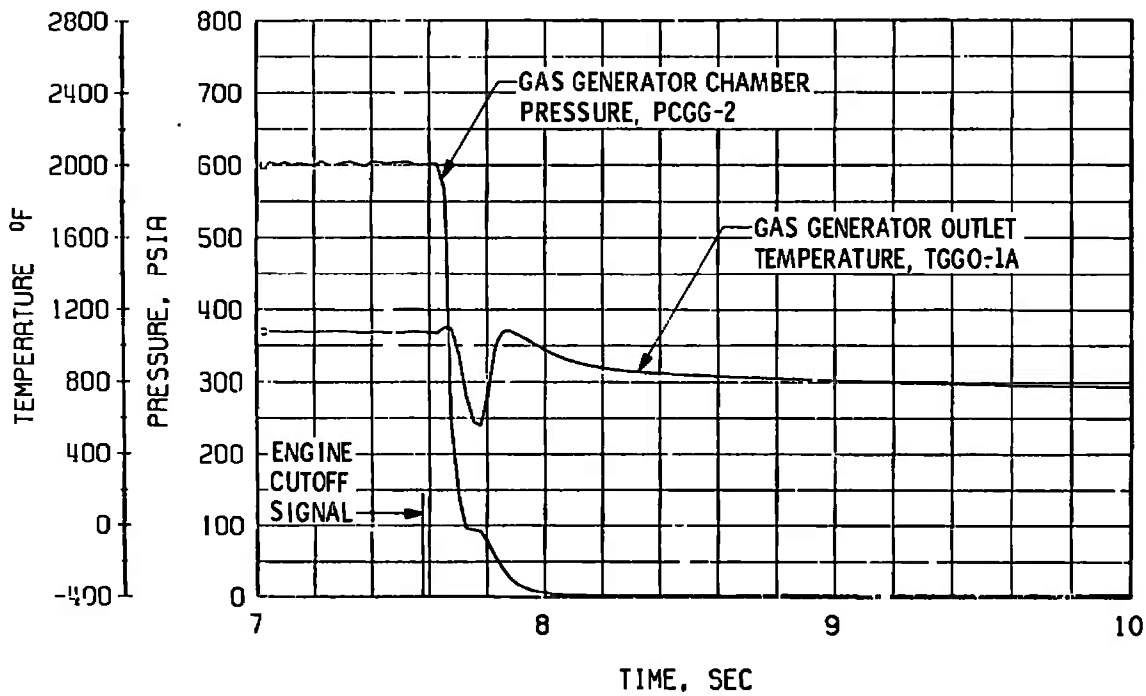


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 42 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 42 Concluded

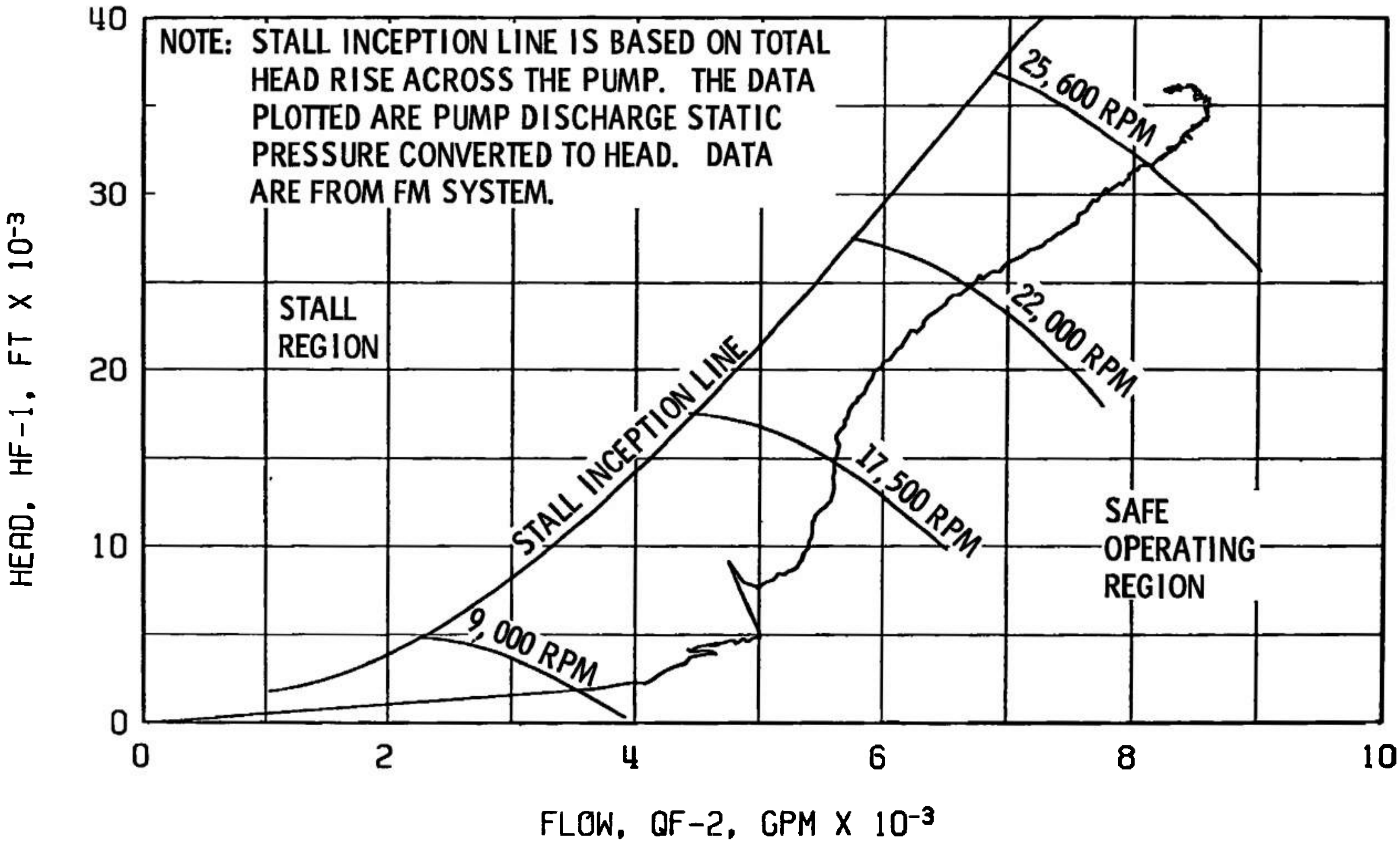
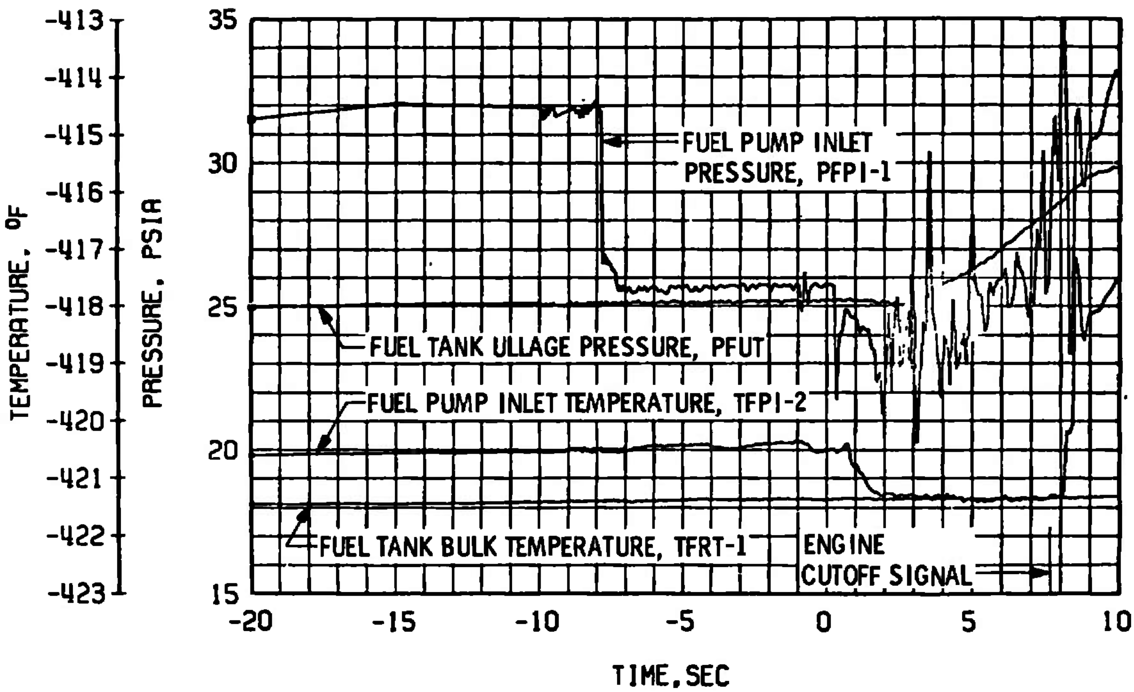
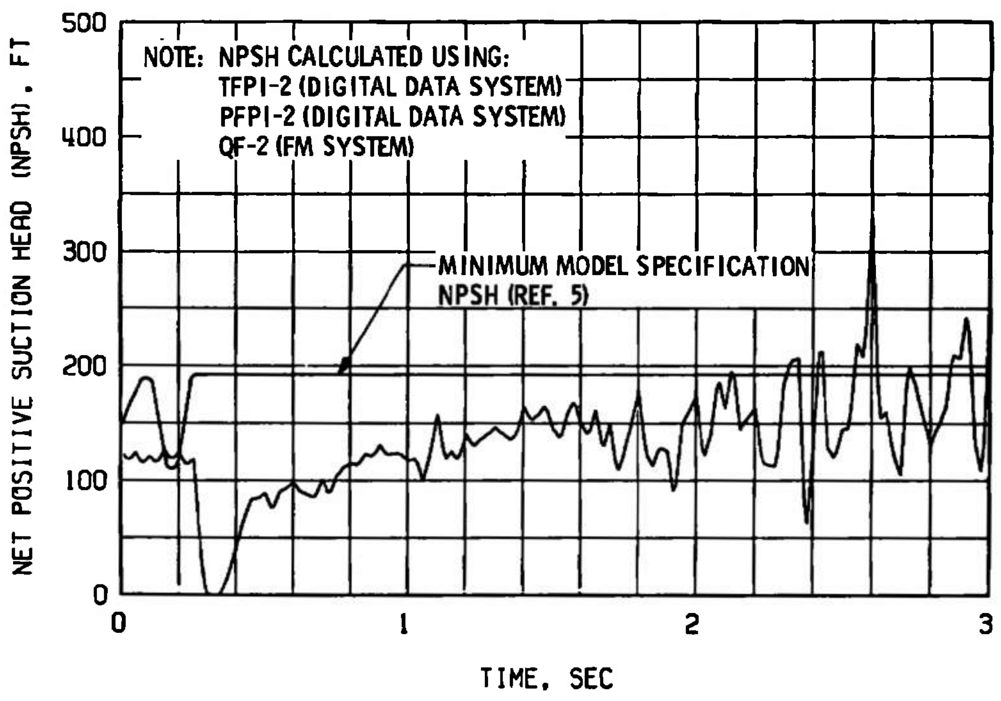


Fig. 43 Fuel Pump Start Transient Performance, Firing 29E

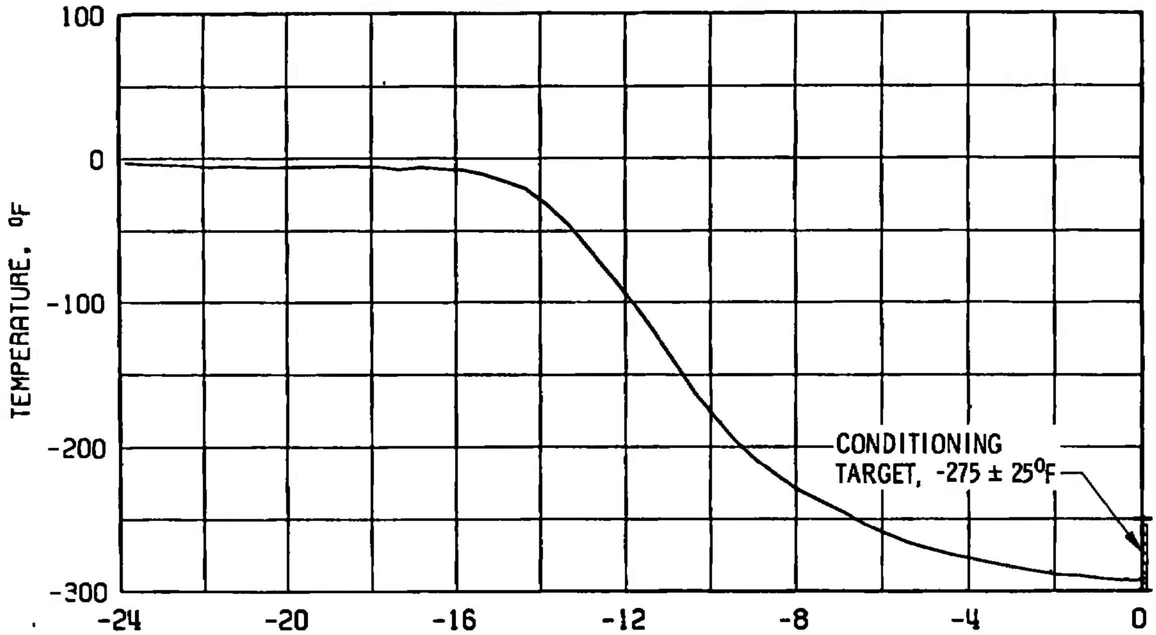


a. Duct Pressure and Temperature Transients

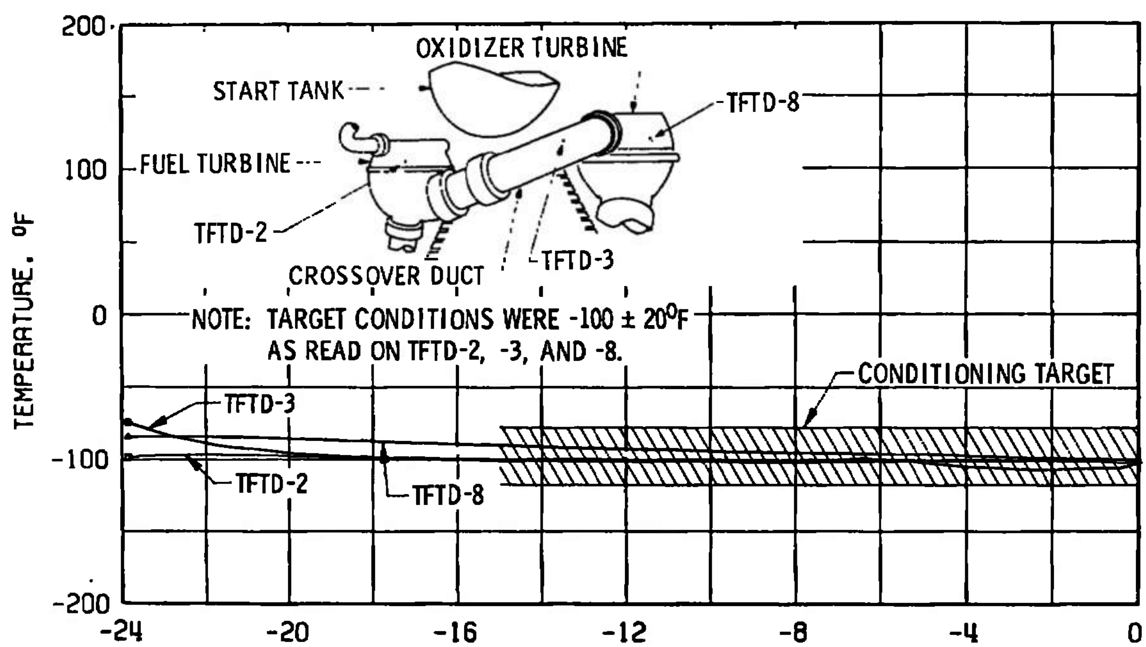


b. Fuel Pump NPSH during Start Transient, Firing 29E

Fig. 44 Fuel Low Pressure Duct Performance, Firing 29E

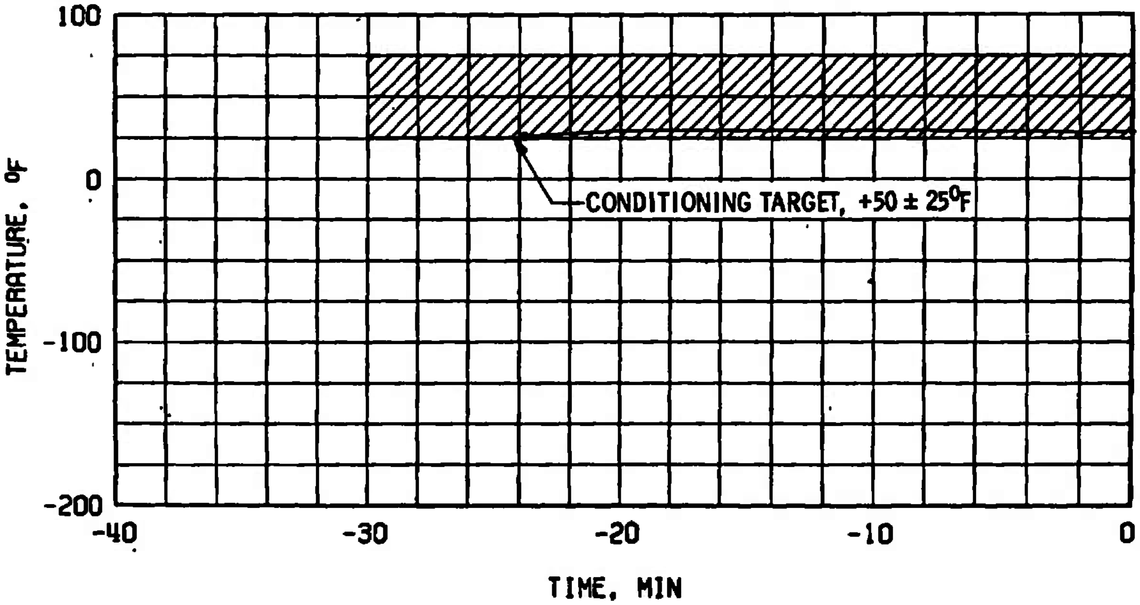


a. Thrust Chamber Throat, TTC-1P

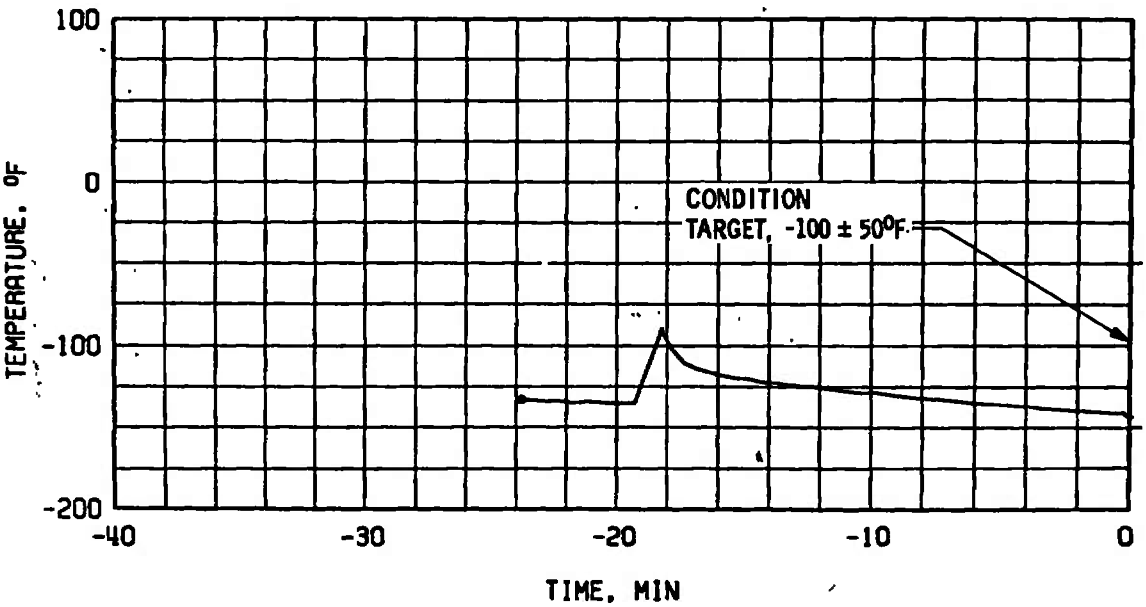


b. Crossover Duct, TFTD

Fig. 45 Thermal Conditioning History of Engine Components, Firing 30A



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 45 Concluded

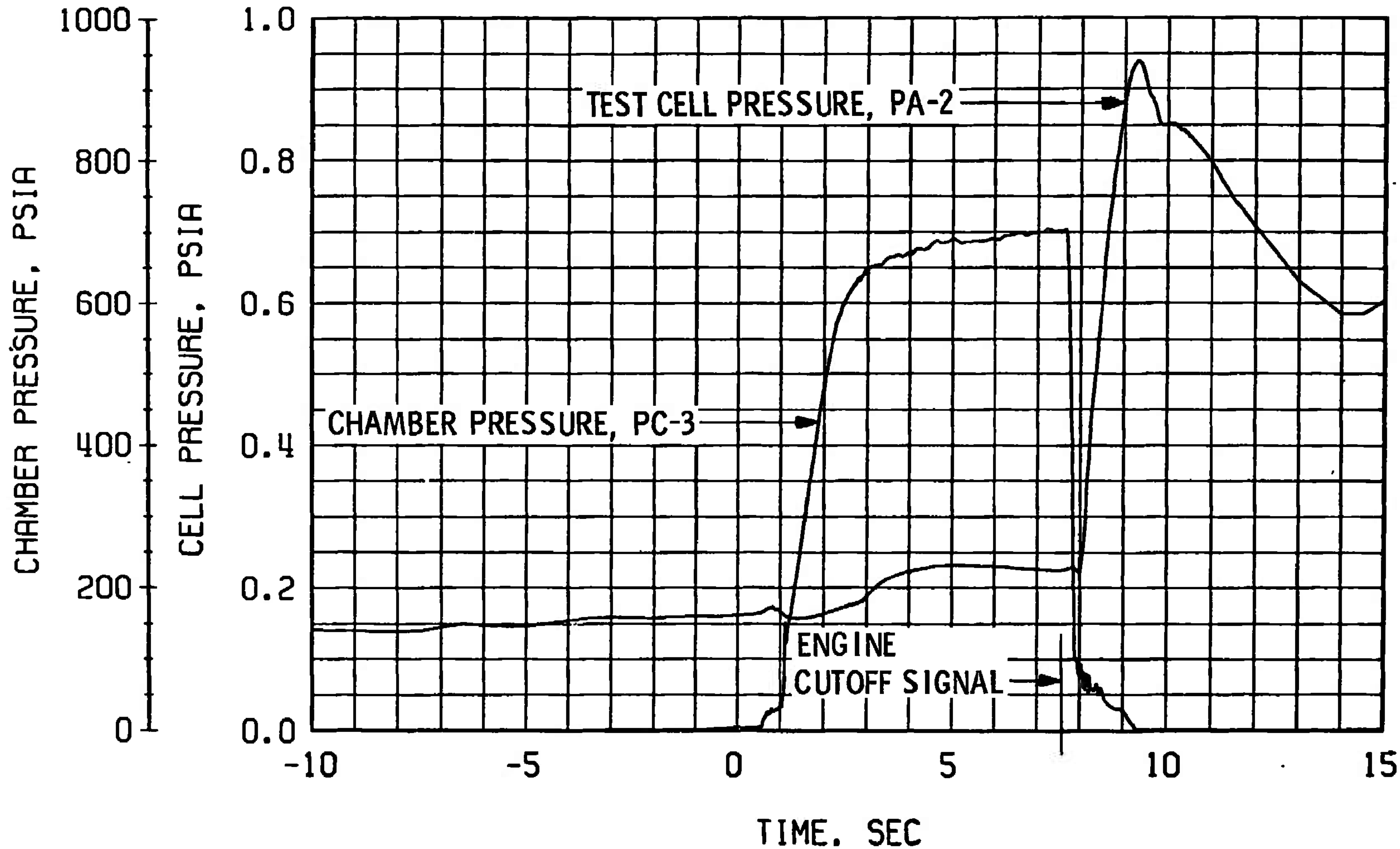
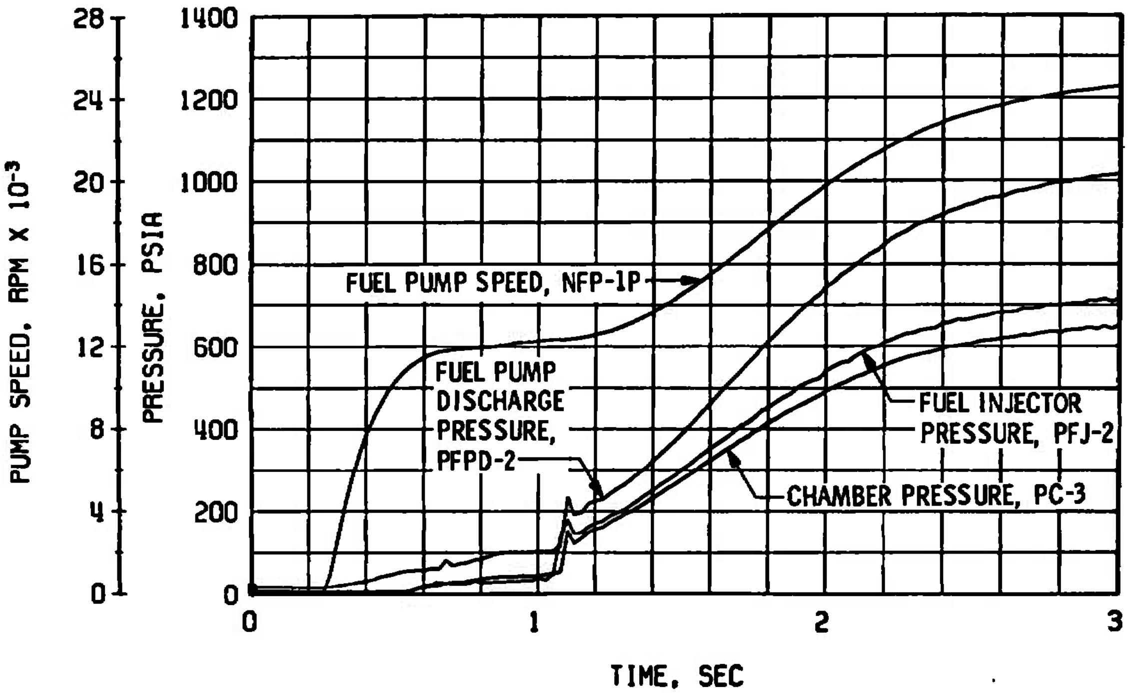
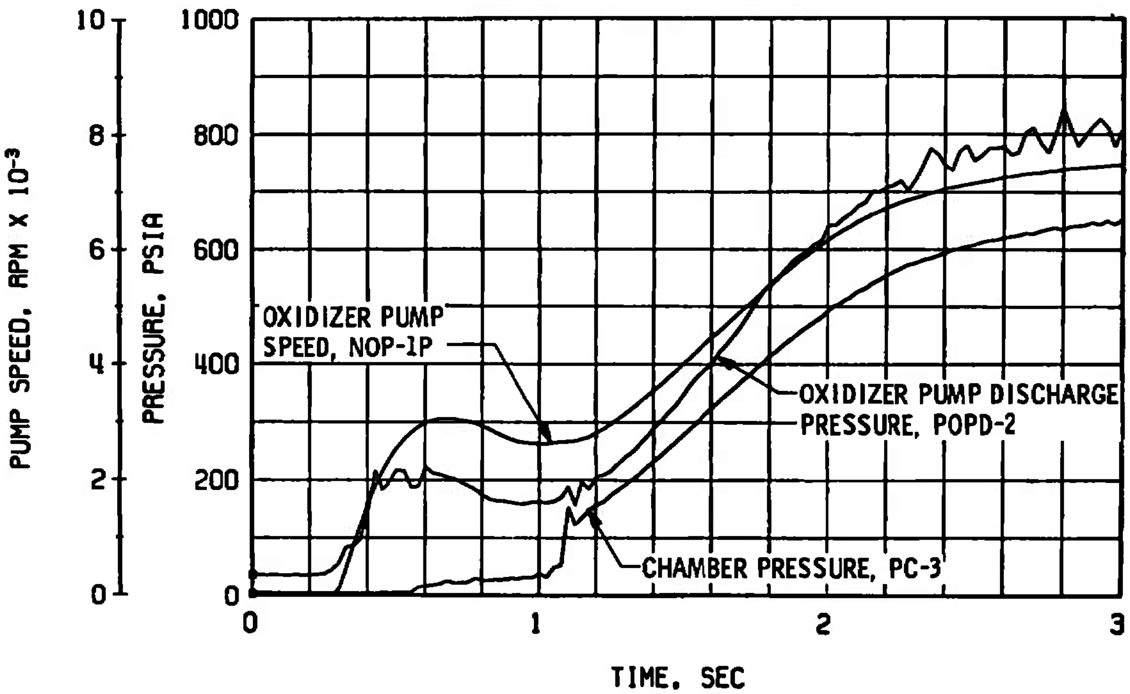


Fig. 46 Engine Ambient and Combustion Chamber Pressures, Firing 30A

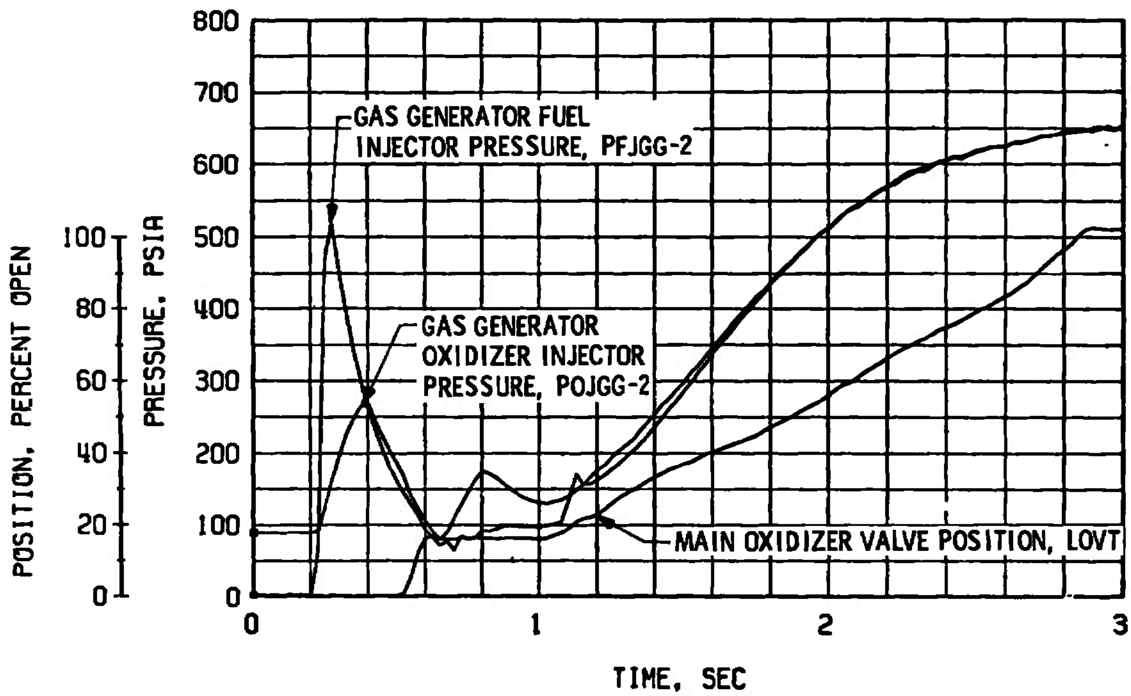


a. Thrust Chamber Fuel System, Start

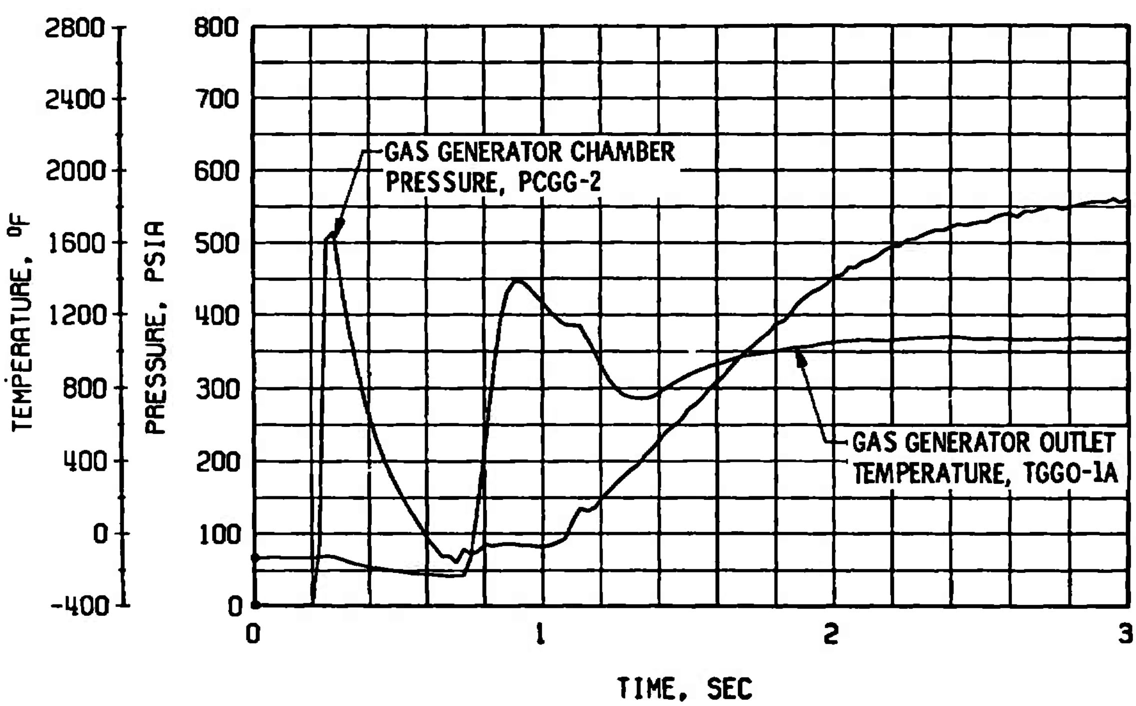


b. Thrust Chamber Oxidizer System, Start

Fig. 47 Engine Transient Operation, Firing 30A

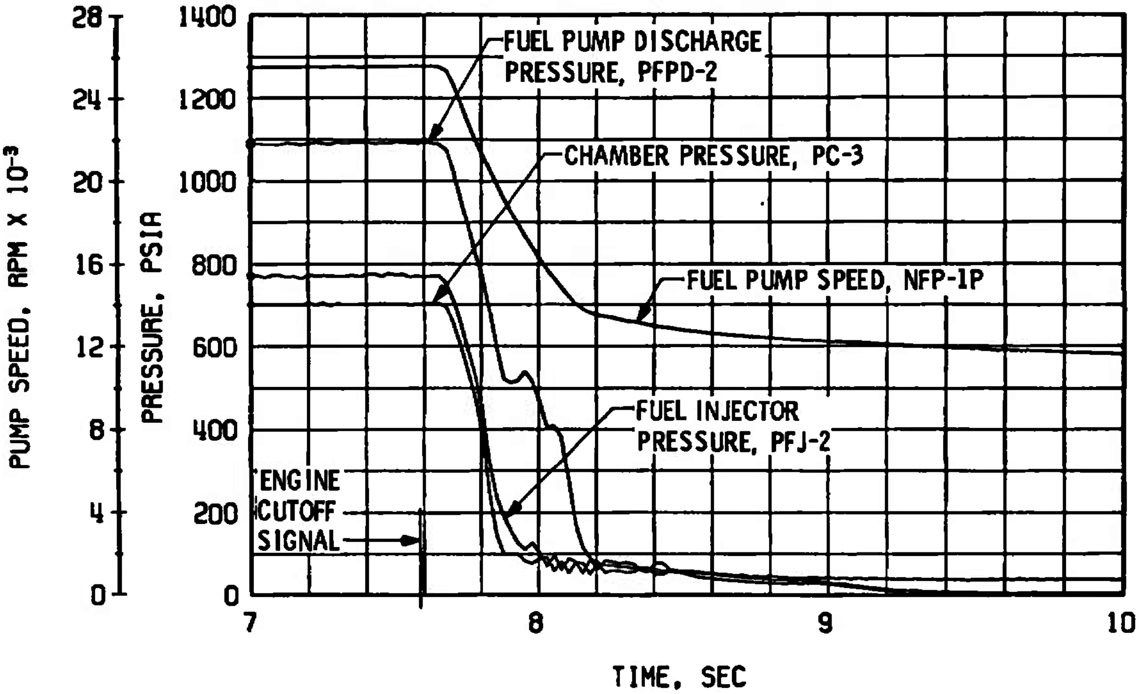


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

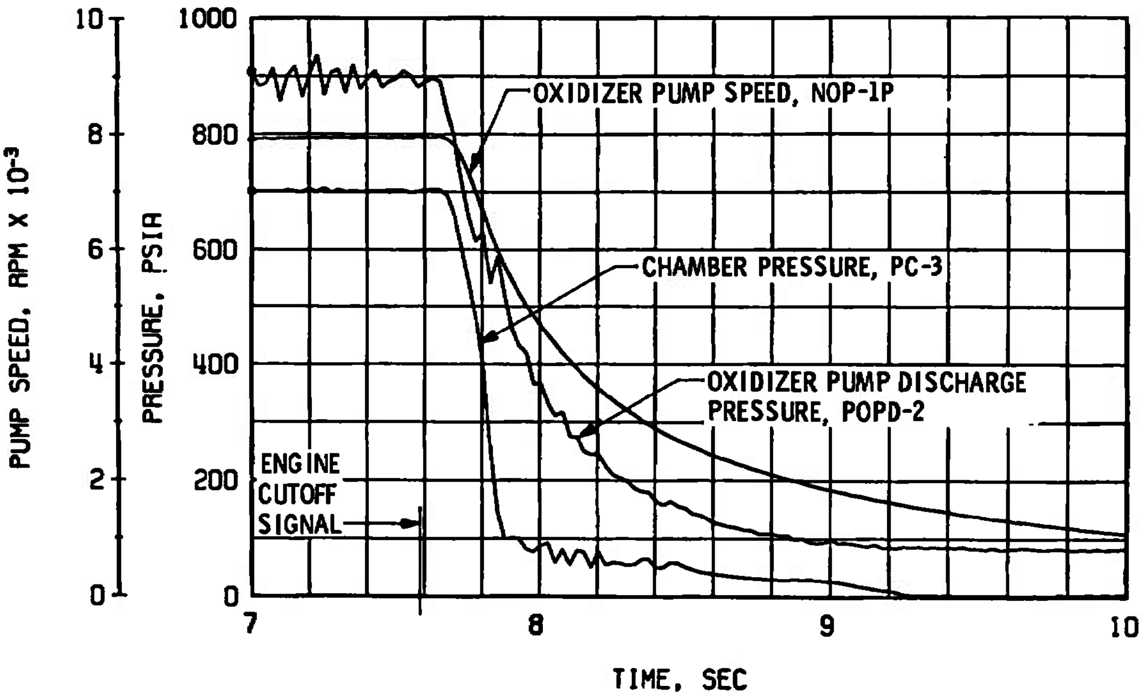


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 47 Continued

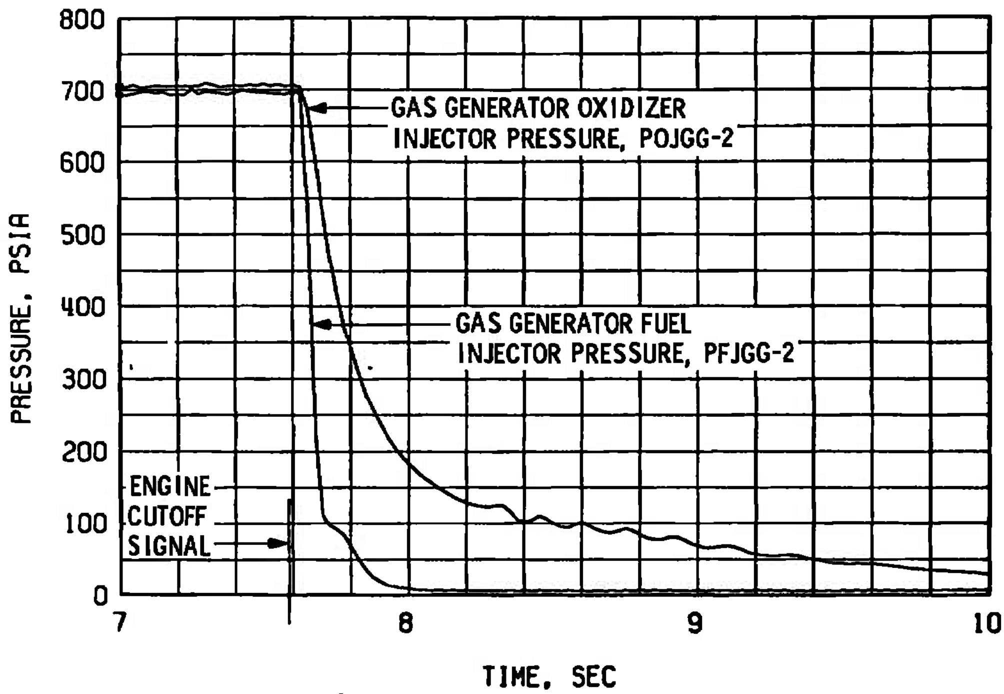


e. Thrust Chamber Fuel System, Shutdown

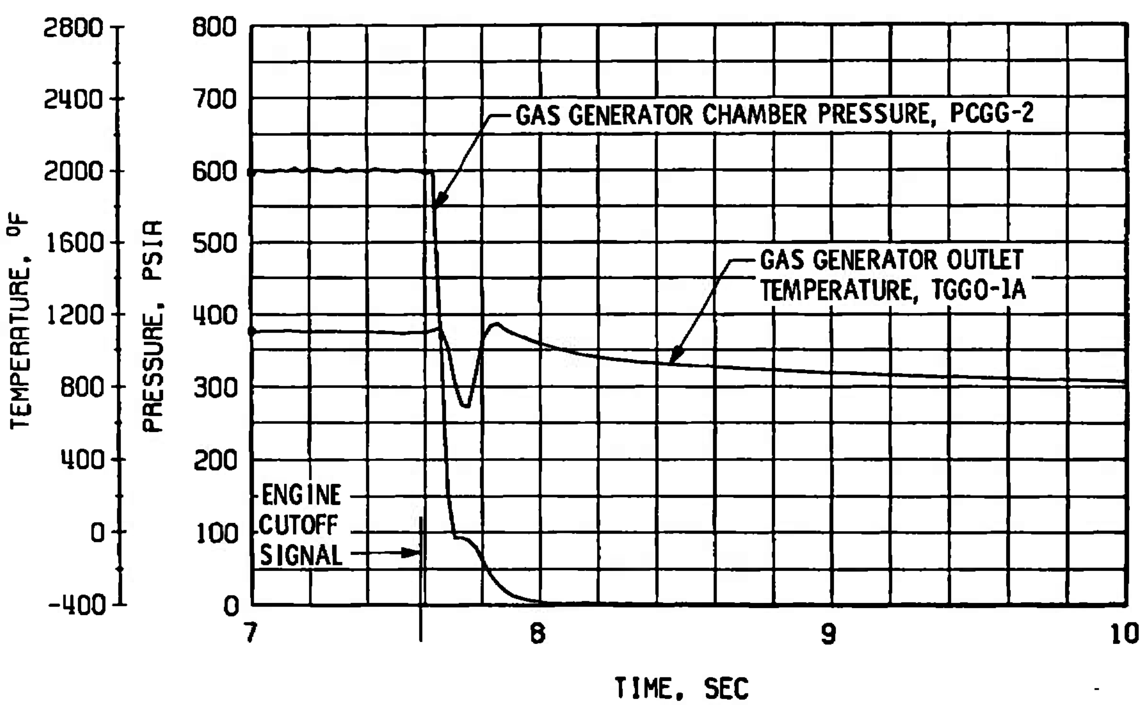


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 47 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 47 Concluded

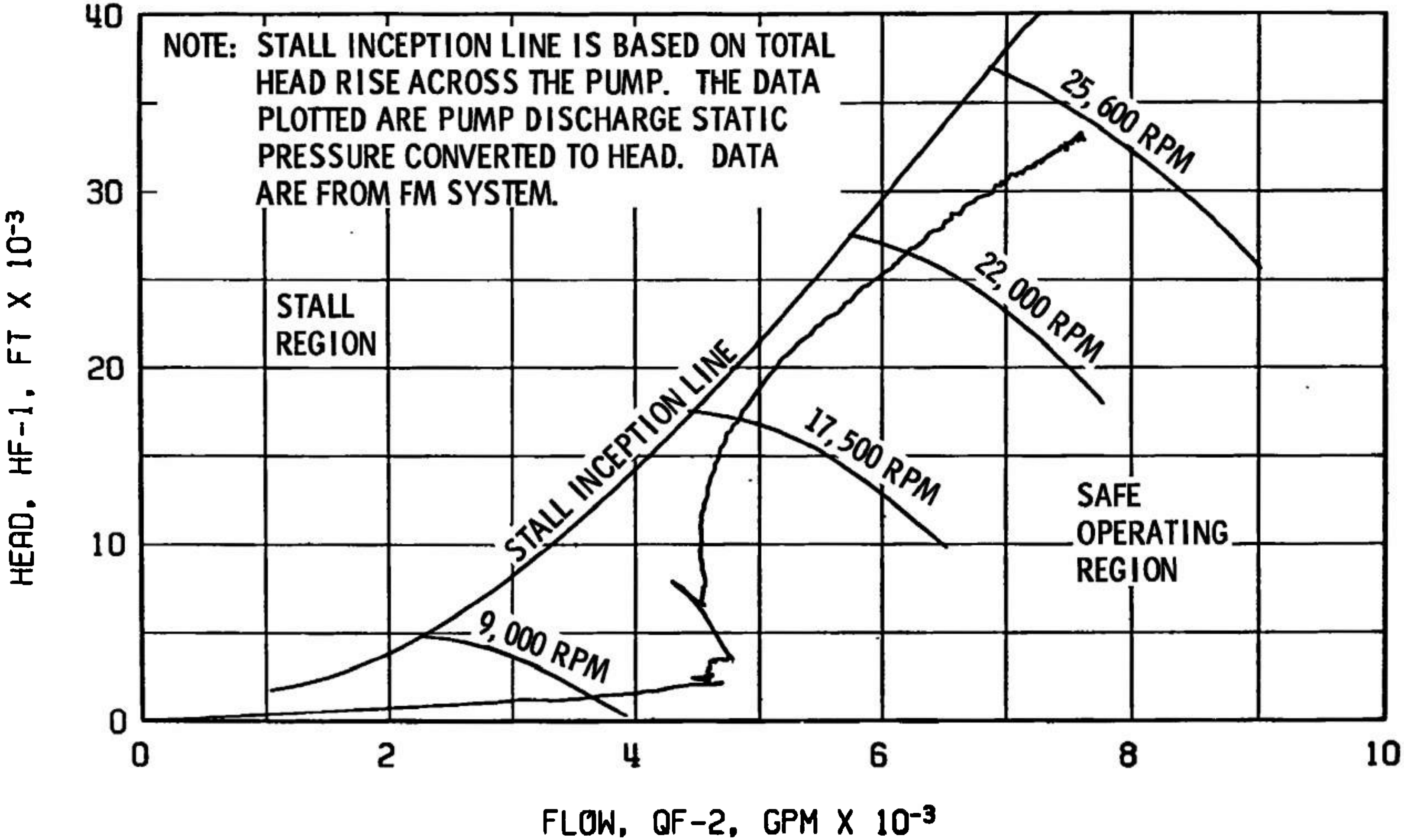
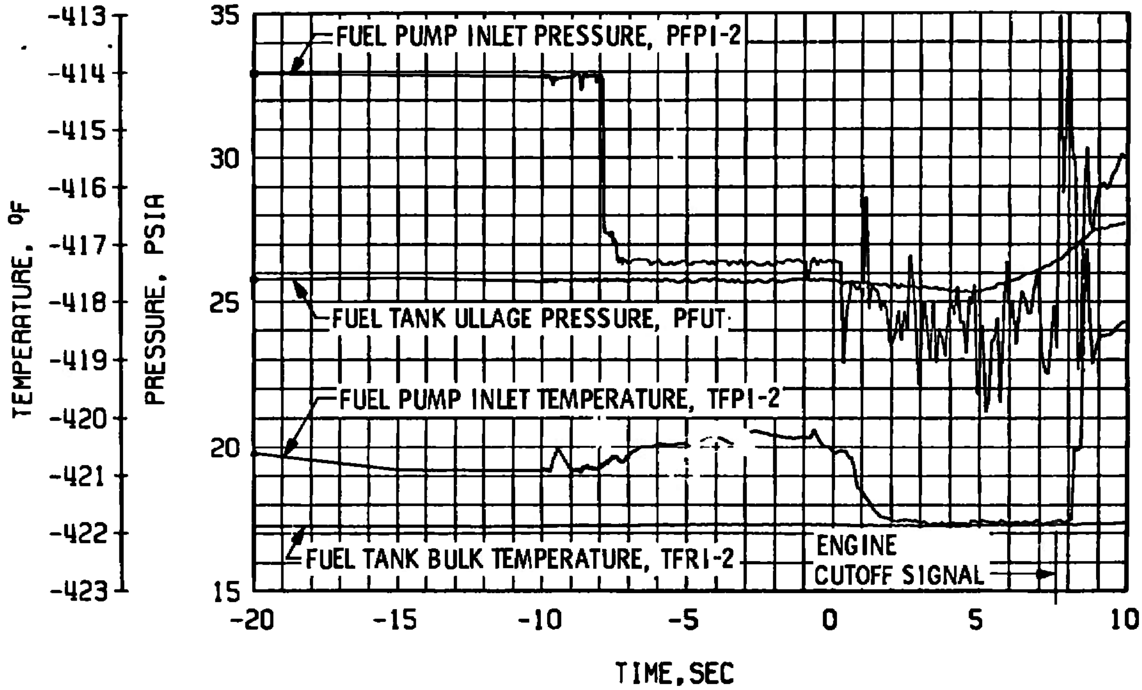
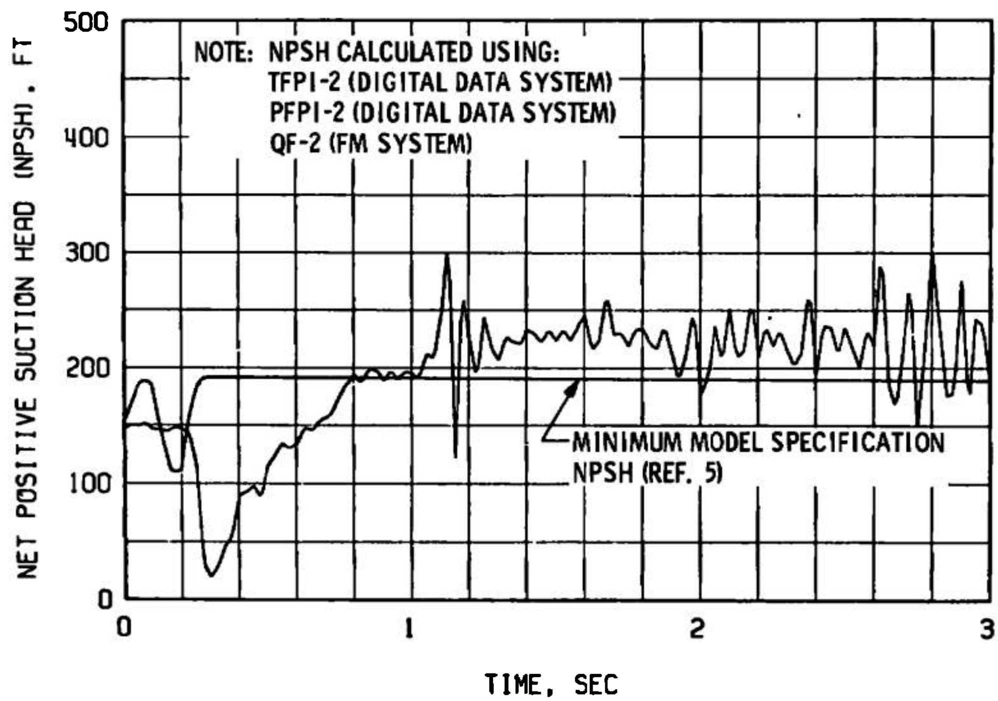


Fig. 48 Fuel Pump Start Transient Performance, Firing 30A

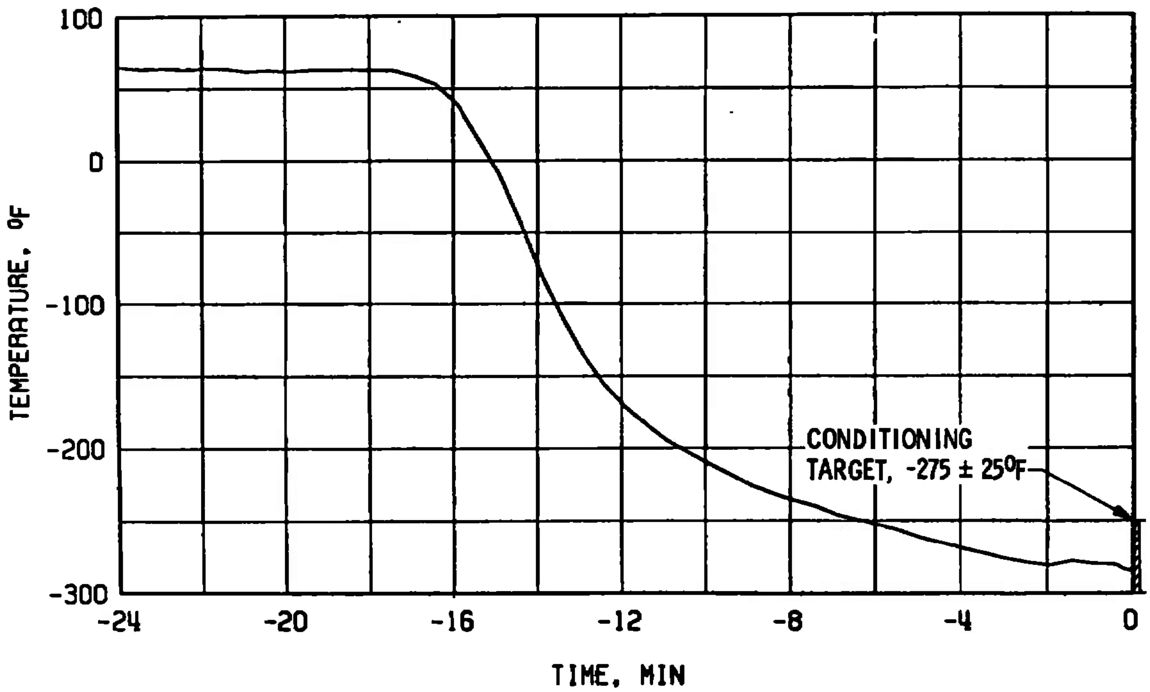


a. Duct Pressure and Temperature Transients

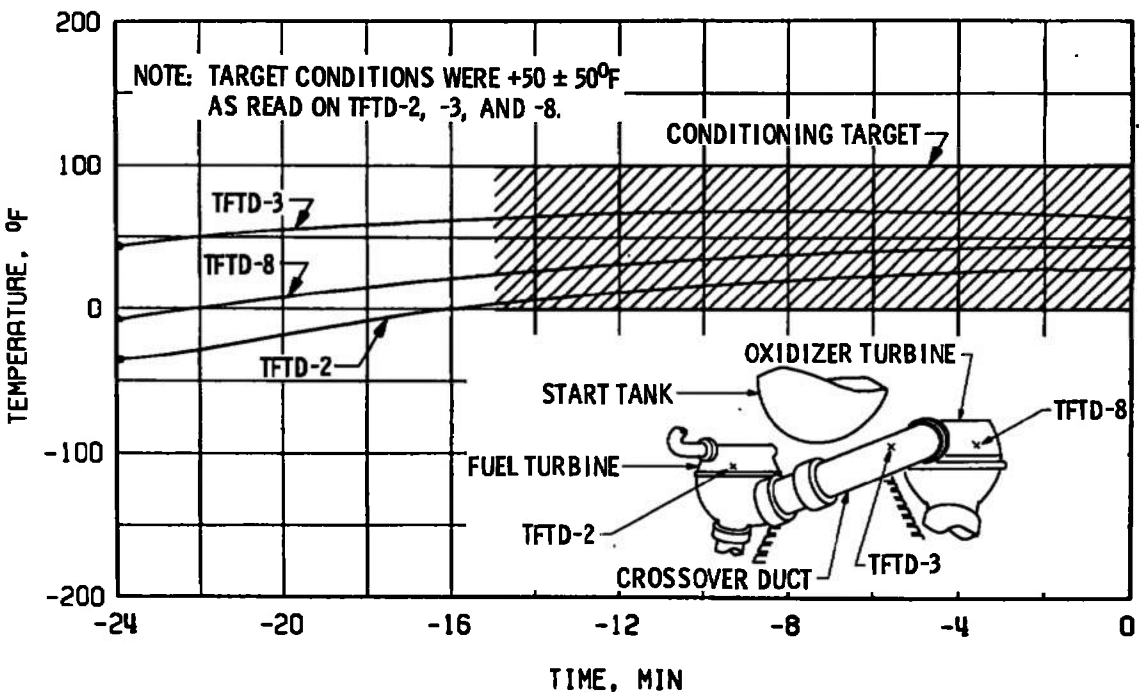


b. Fuel Pump NPSH during Start Transient, Firing 30A

Fig. 49 Fuel Low Pressure Duct Performance, Firing 30A

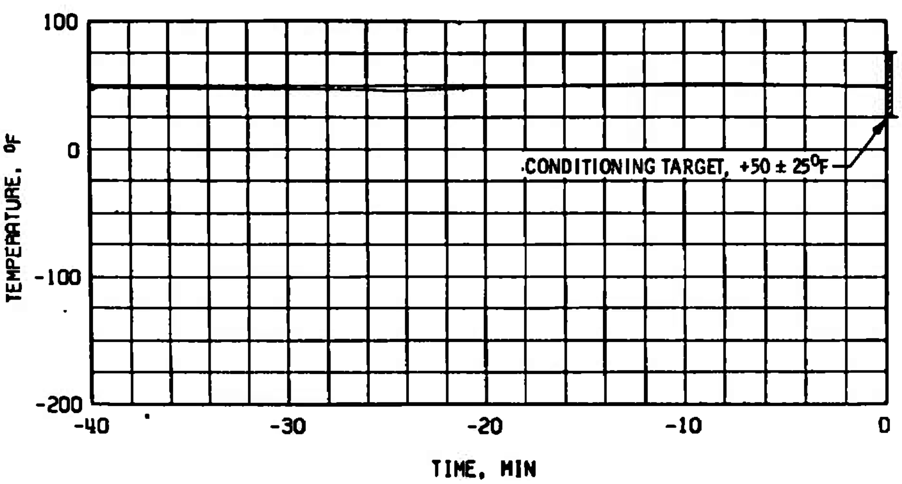


a. Thrust Chamber Throat, TTC-1P

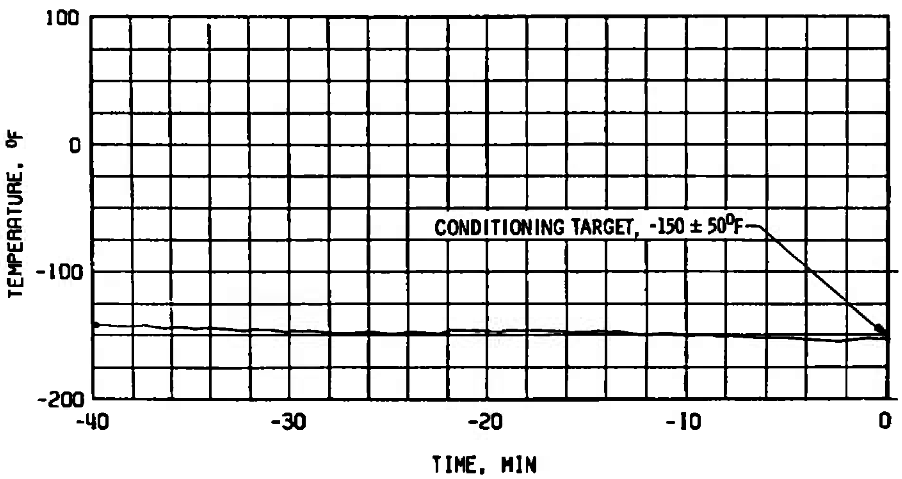


b. Crossover Duct, TFTD

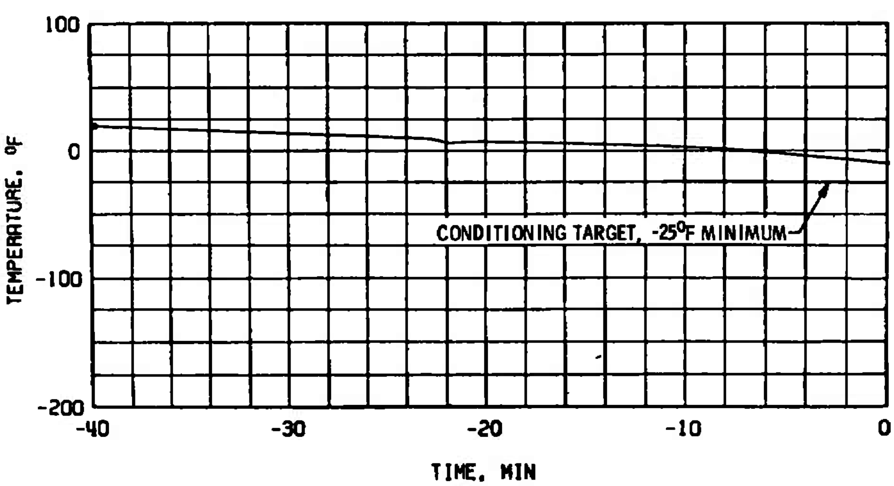
Fig. 50 Thermal Conditioning History of Engine Components, Firing 31A



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1



e. Gas Generator Valve Body, TGGVRS

Fig. 50 Concluded

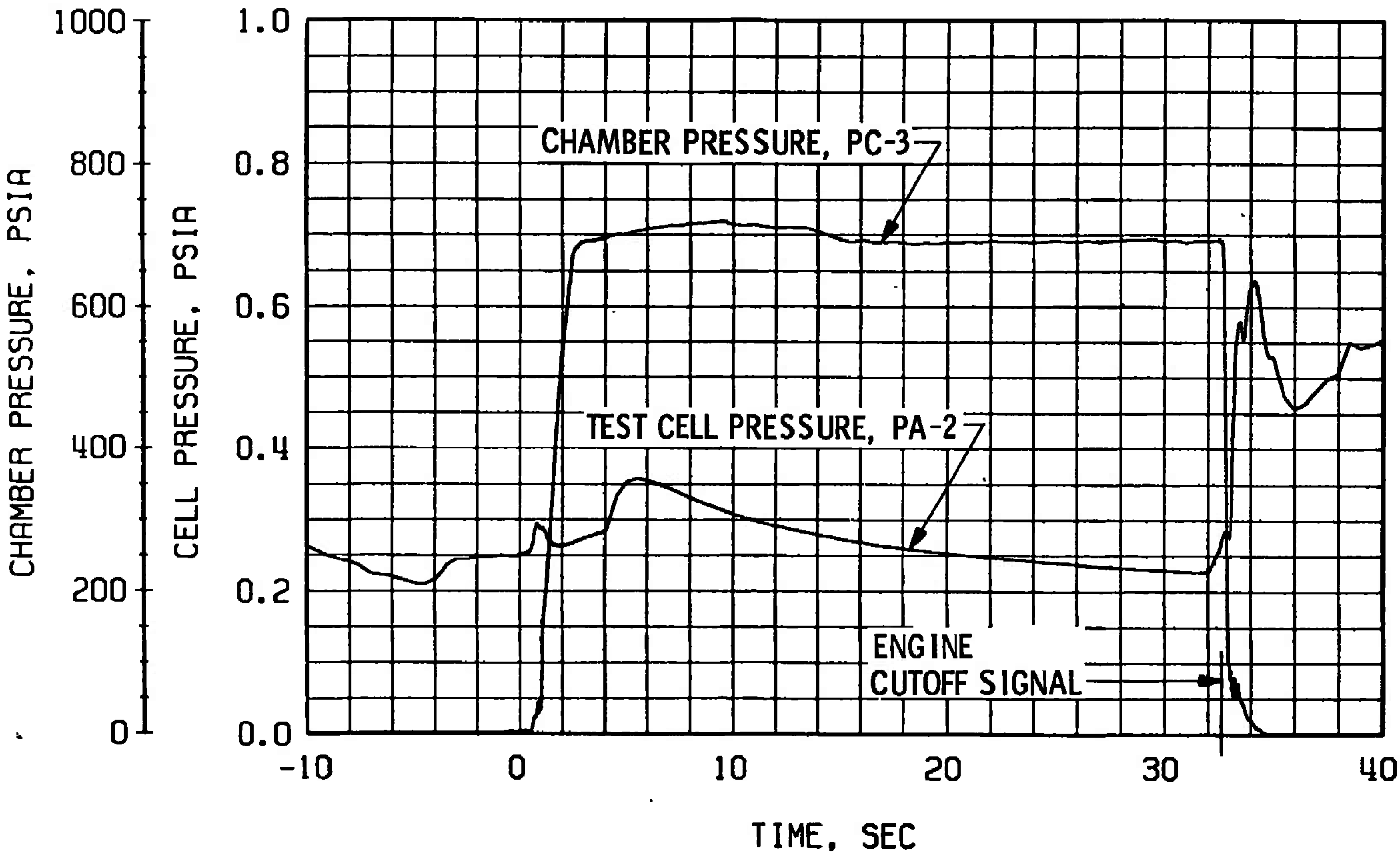
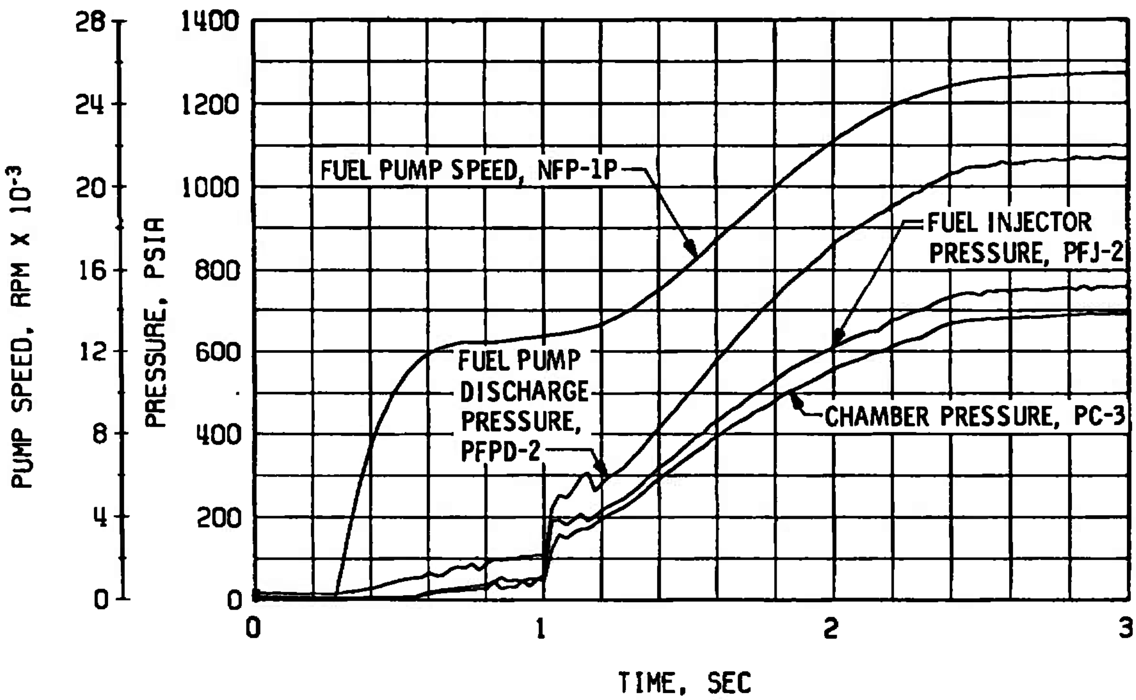
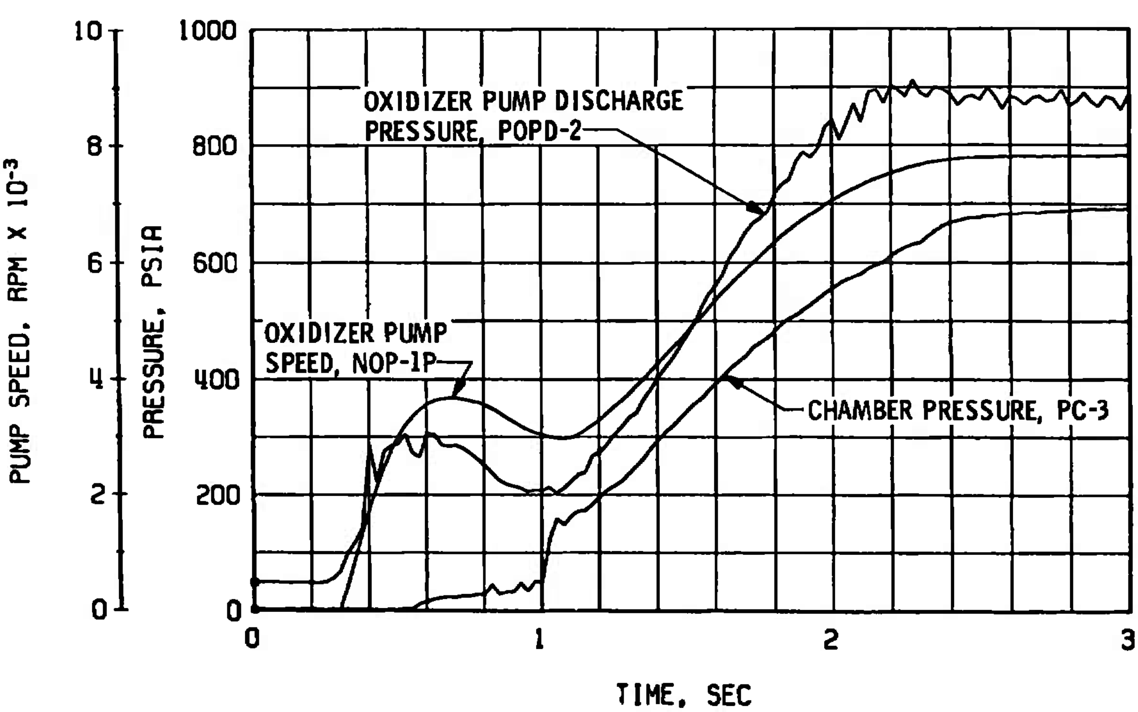


Fig. 51 Engine Ambient and Combustion Chamber Pressures, Firing 31A

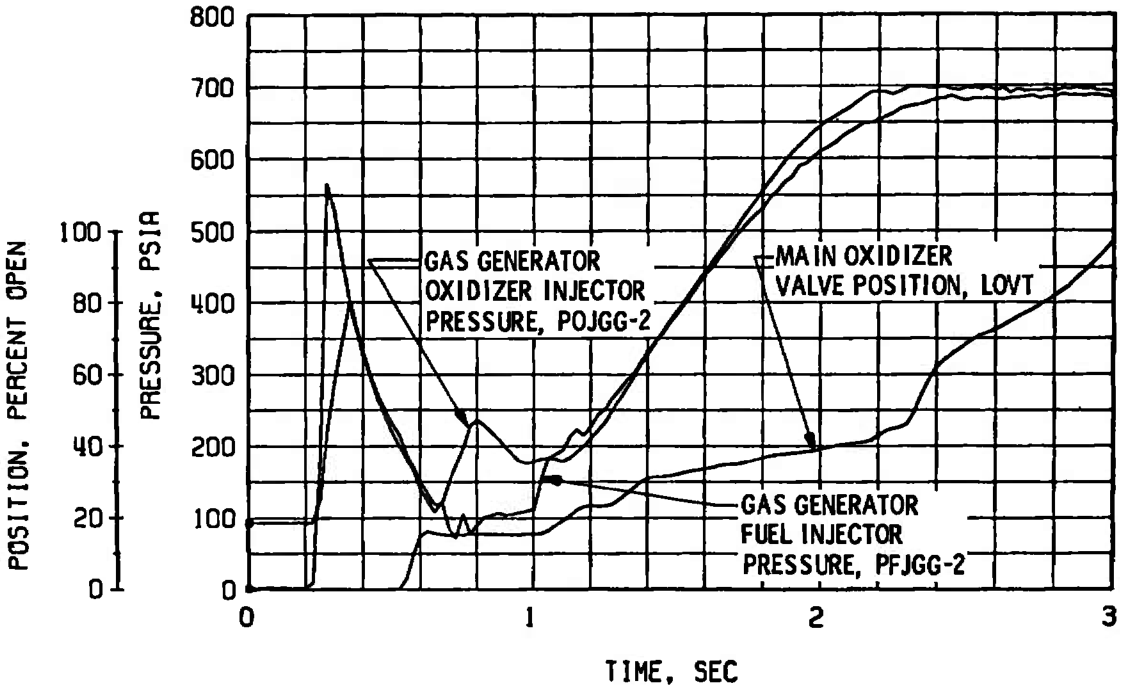


a. Thrust Chamber Fuel System, Start

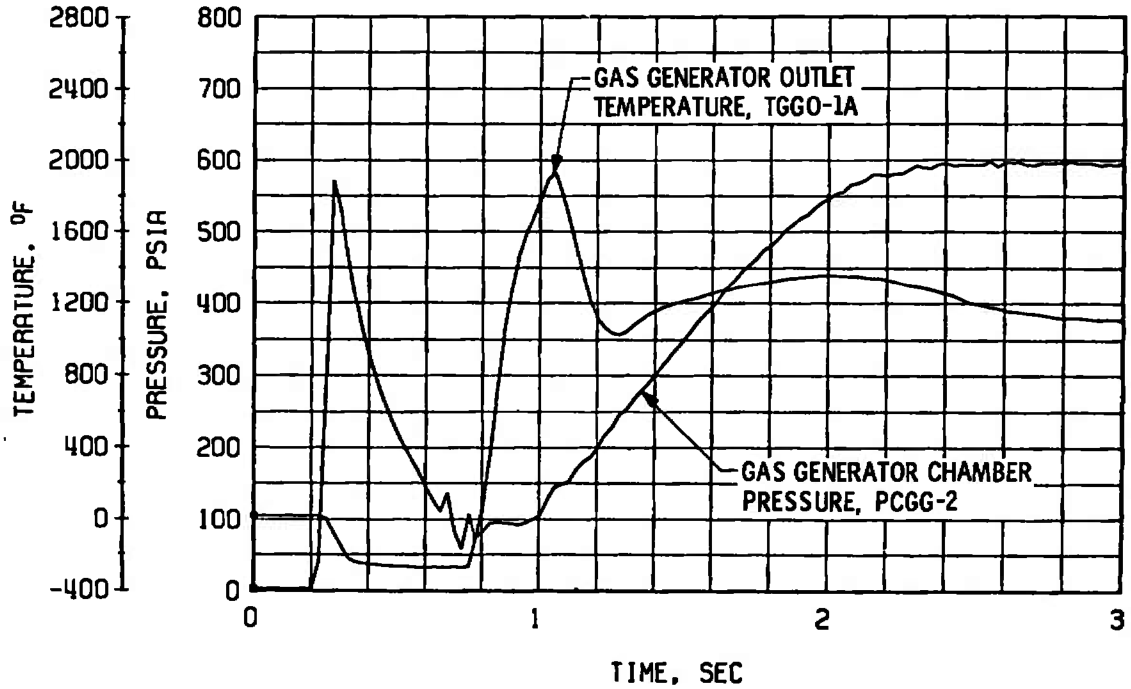


b. Thrust Chamber Oxidizer System, Start

Fig. 52 Engine Transient Operation, Firing 31A

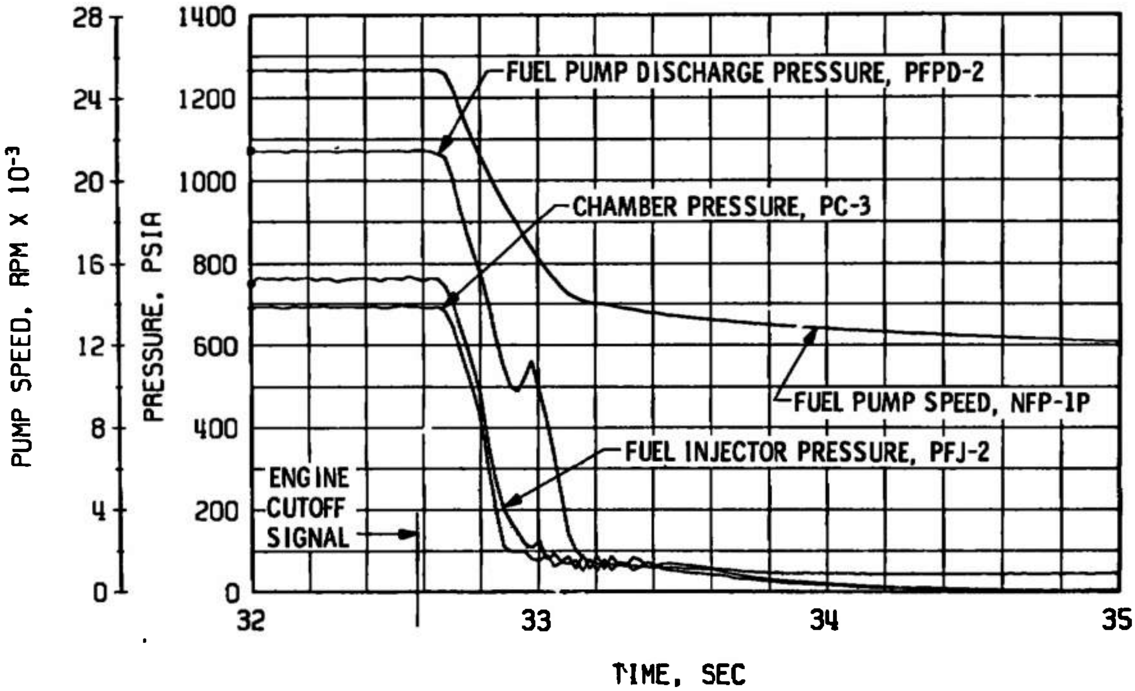


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

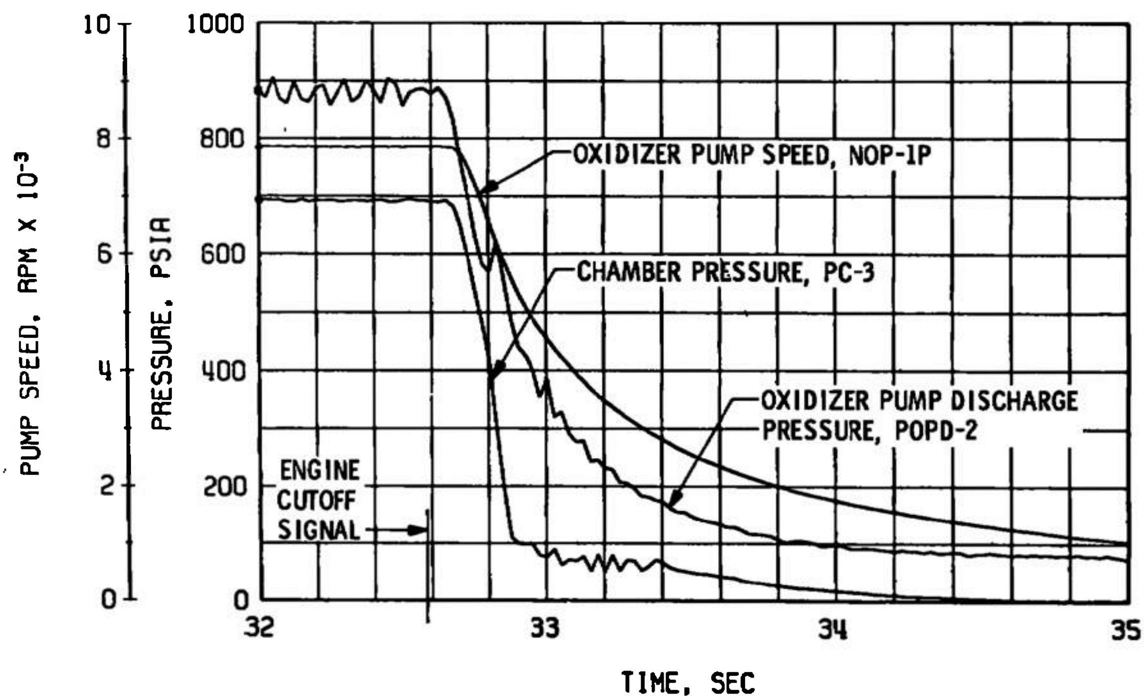


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 52 Continued

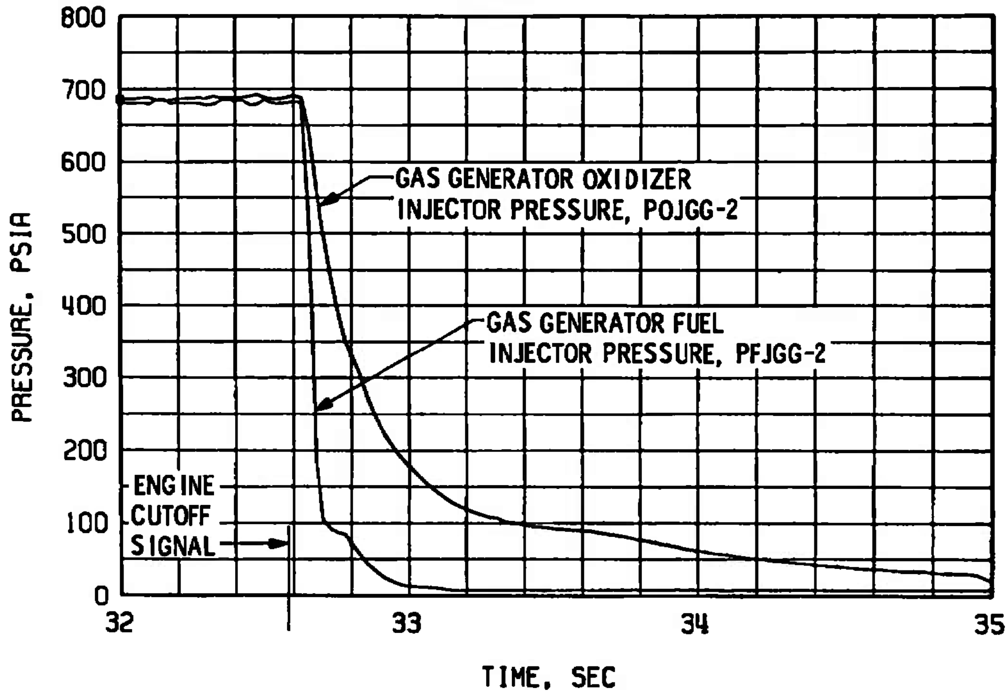


e. Thrust Chamber Fuel System, Shutdown

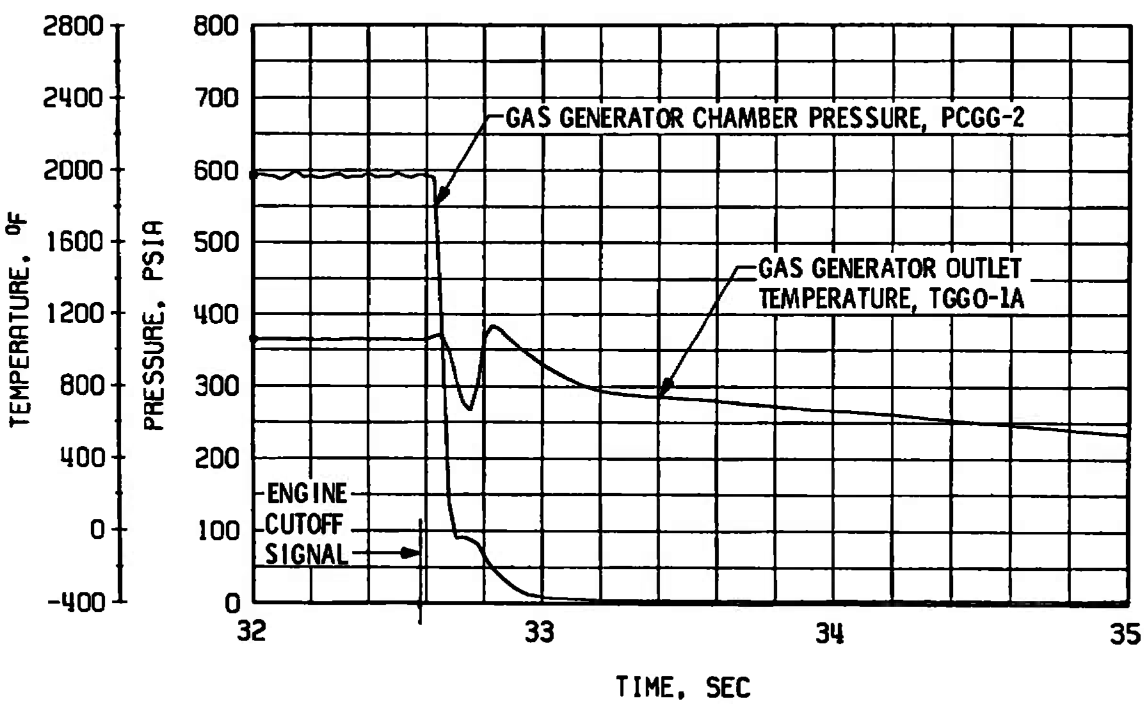


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 52 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 52 Concluded

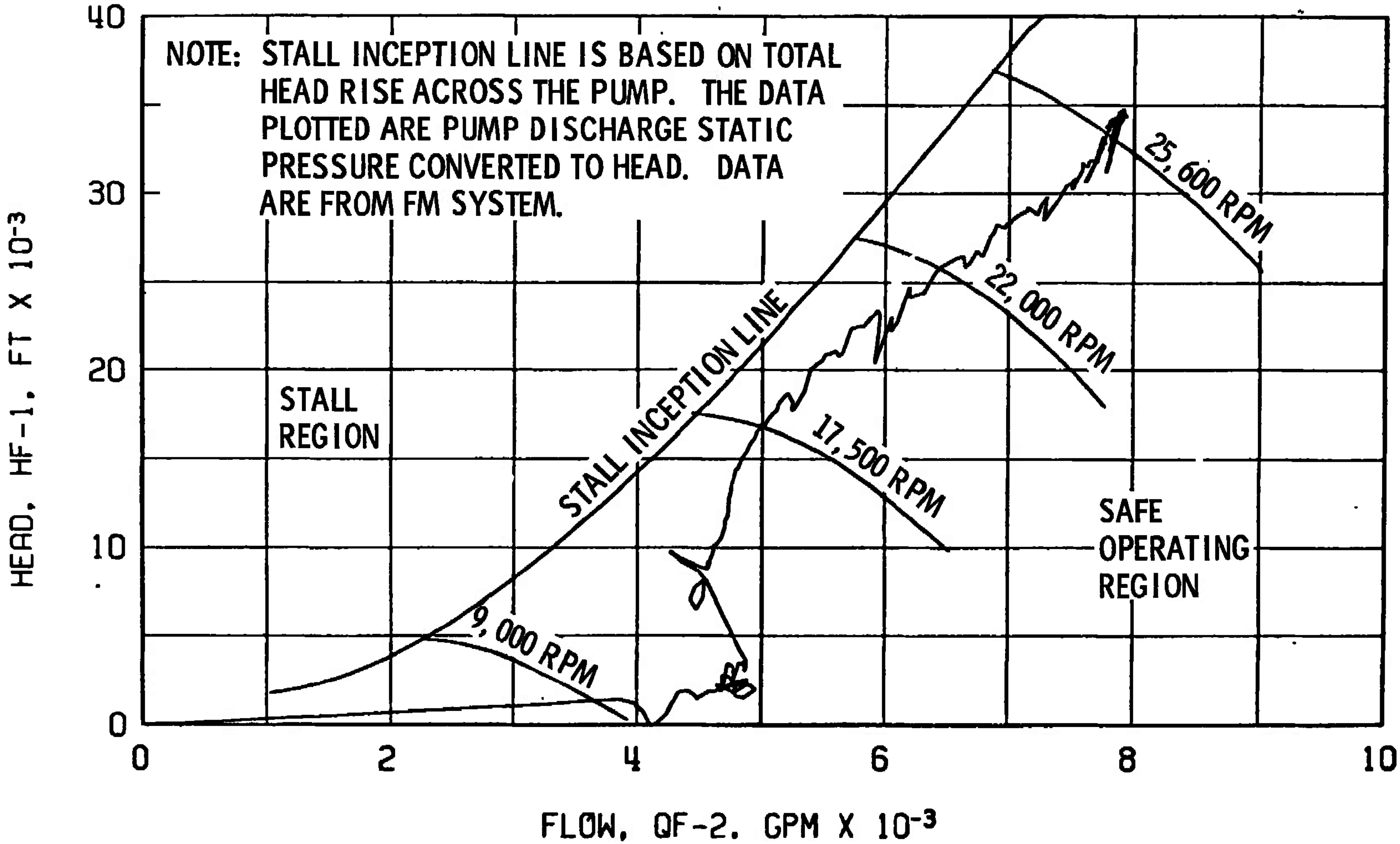
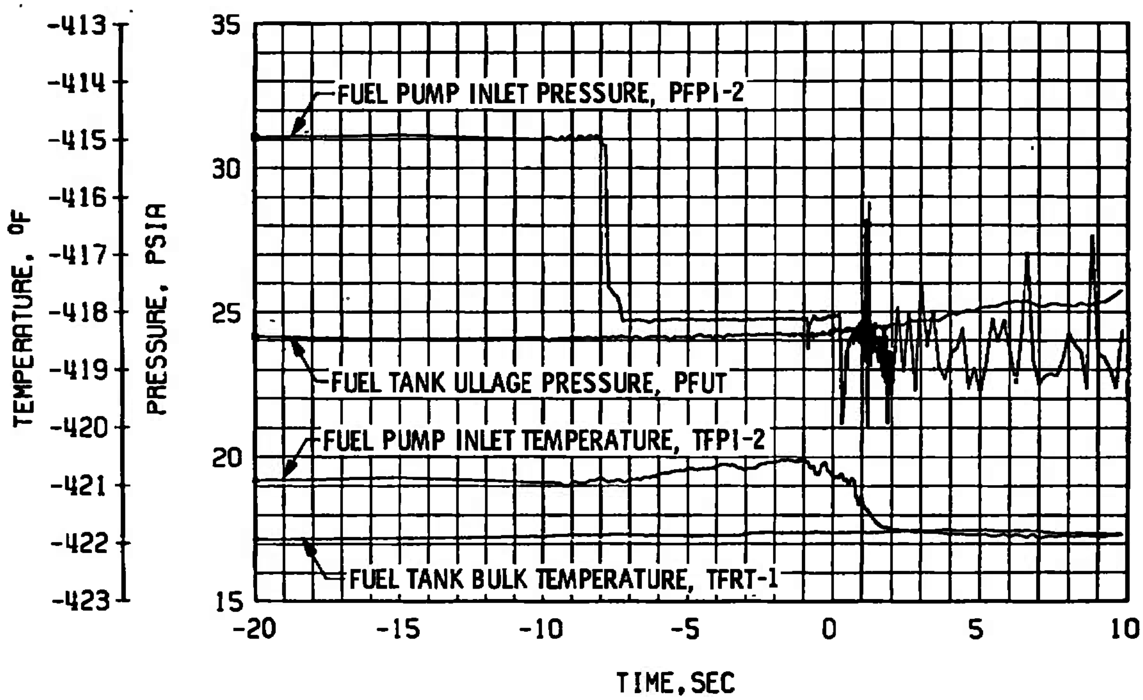
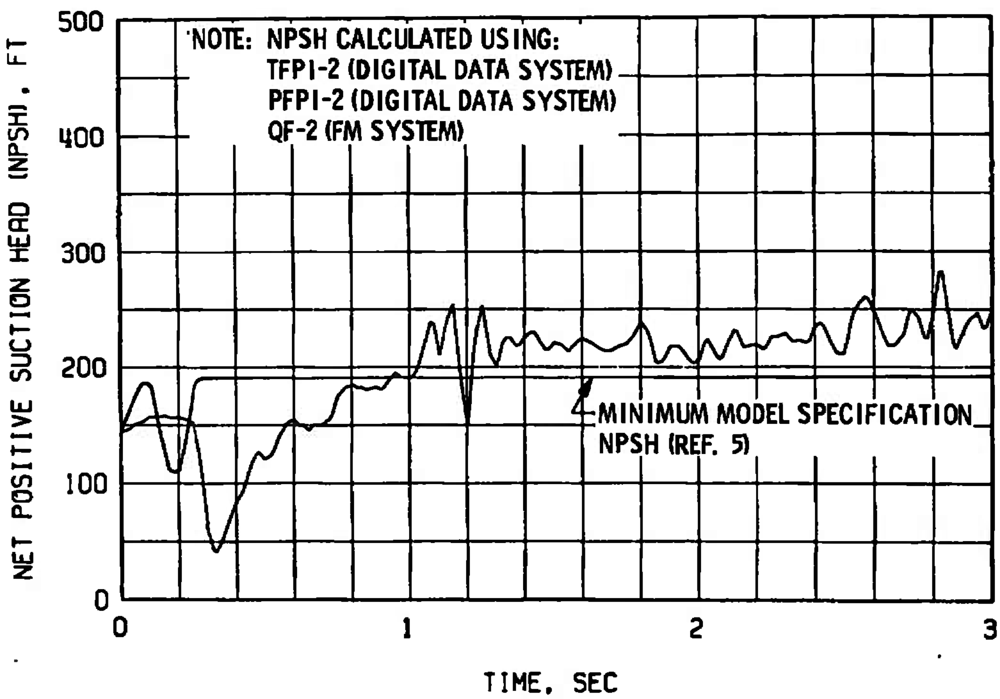


Fig. 53 Fuel Pump Start Transient Performance, Firing 31A

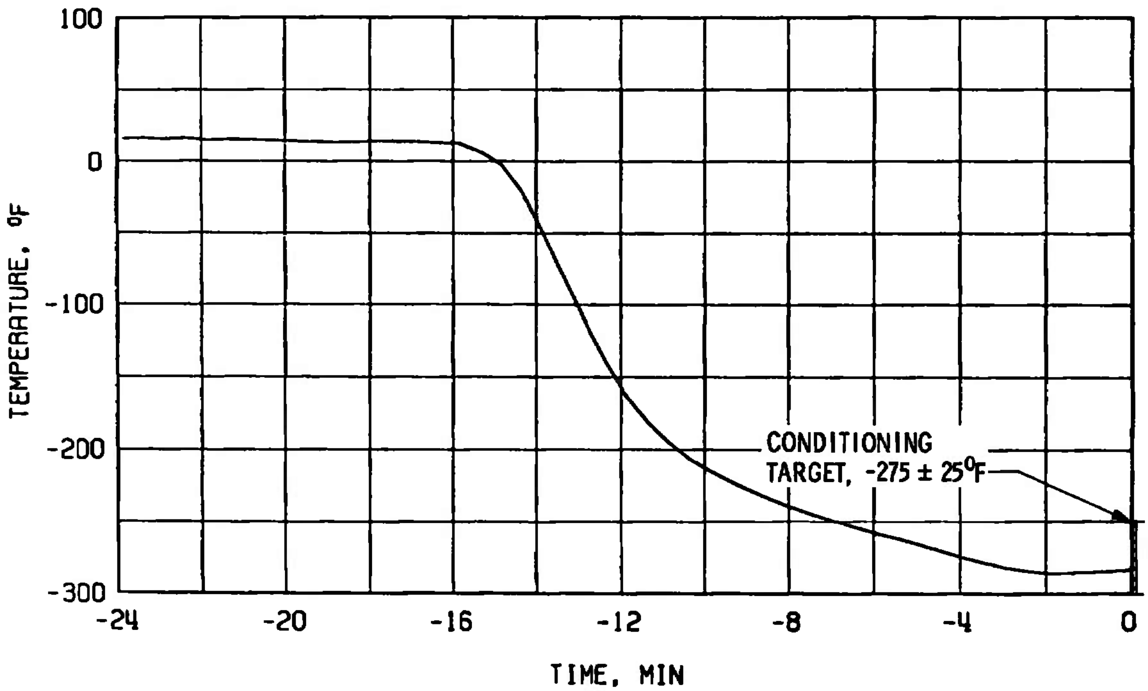


a. Duct Pressure and Temperature Transients

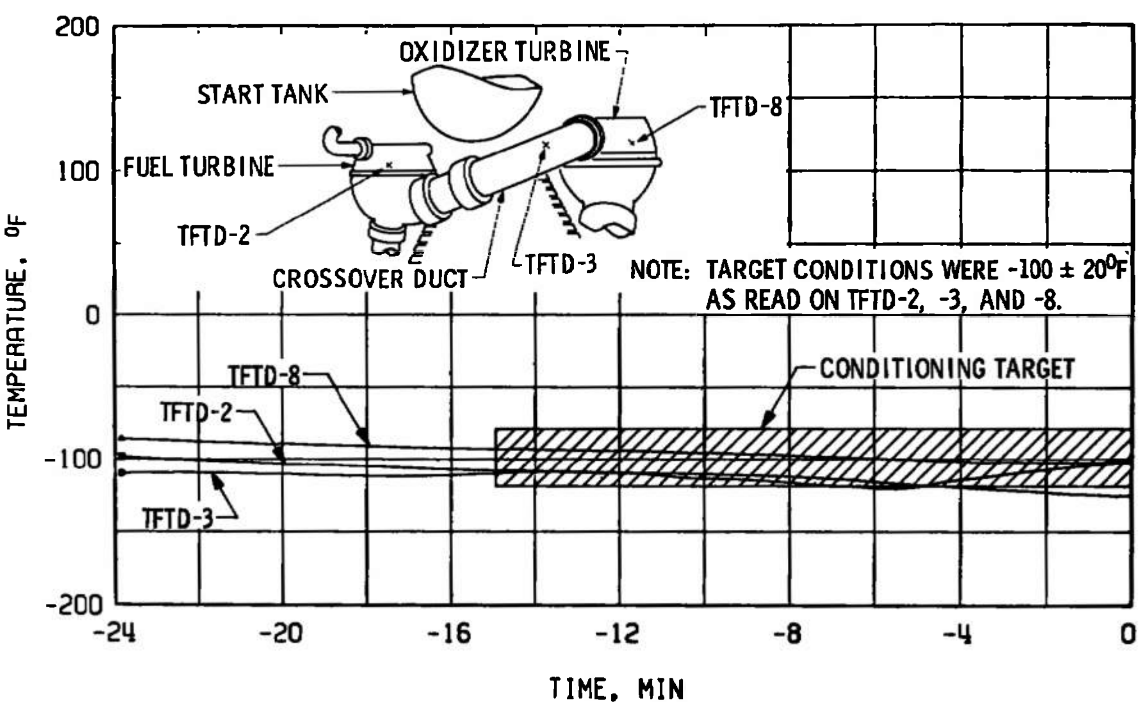


b. Fuel Pump NPSH during Start Transient, Firing 31A

Fig. 54 Fuel Low Pressure Duct Performance, Firing 31A

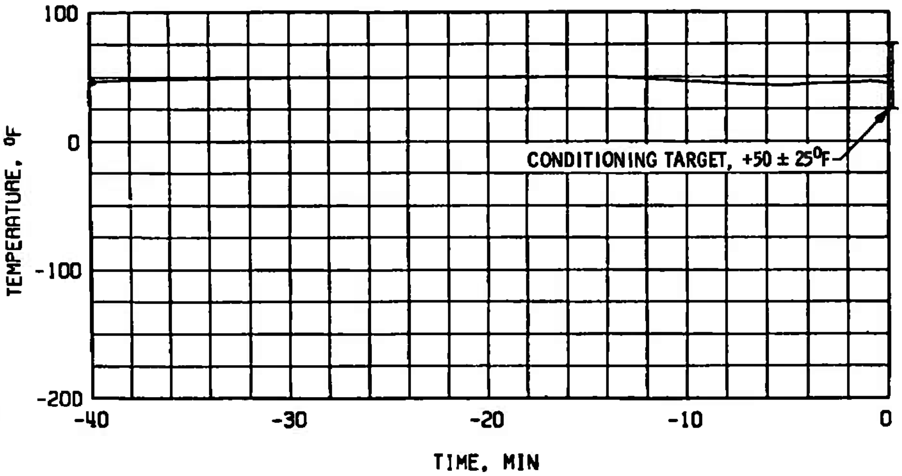


a. Thrust Chamber Throat, TTC-1P

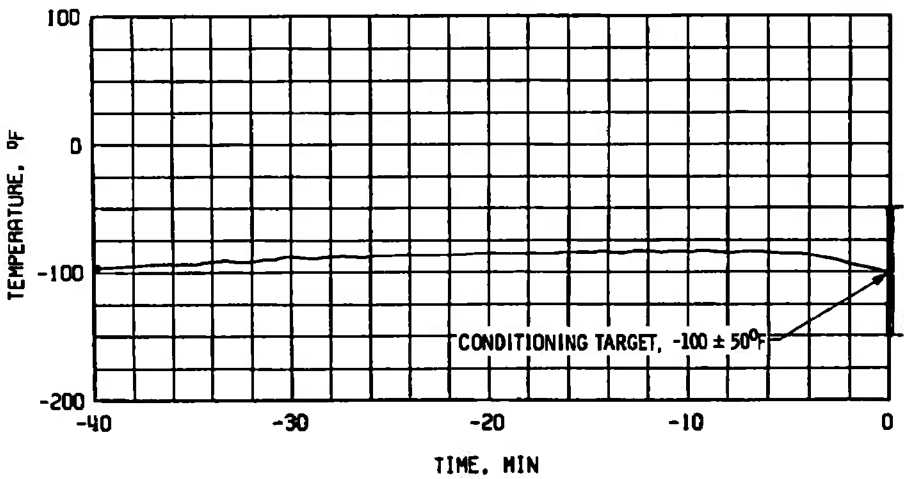


b. Crossover Duct, TFTD

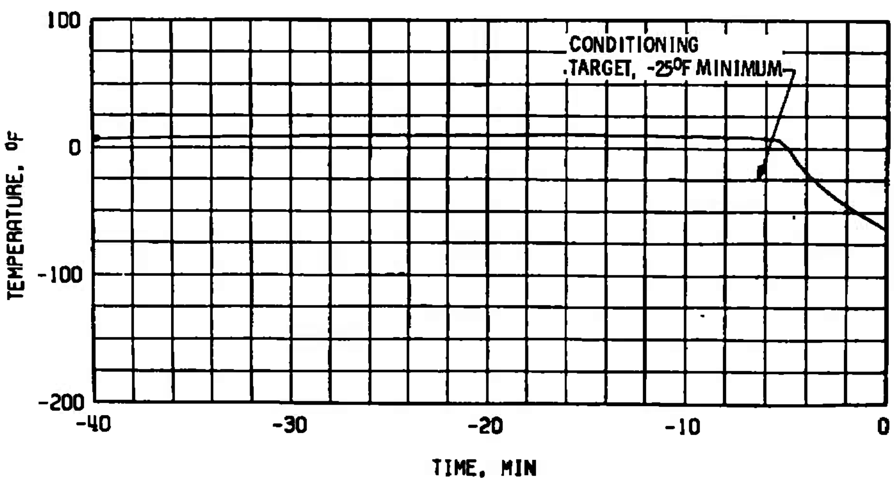
Fig. 55 Thermal Conditioning History of Engine Components, Firing 31B



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1



e. Gas Generator Valve Body, TGGVRS

Fig. 55 Concluded

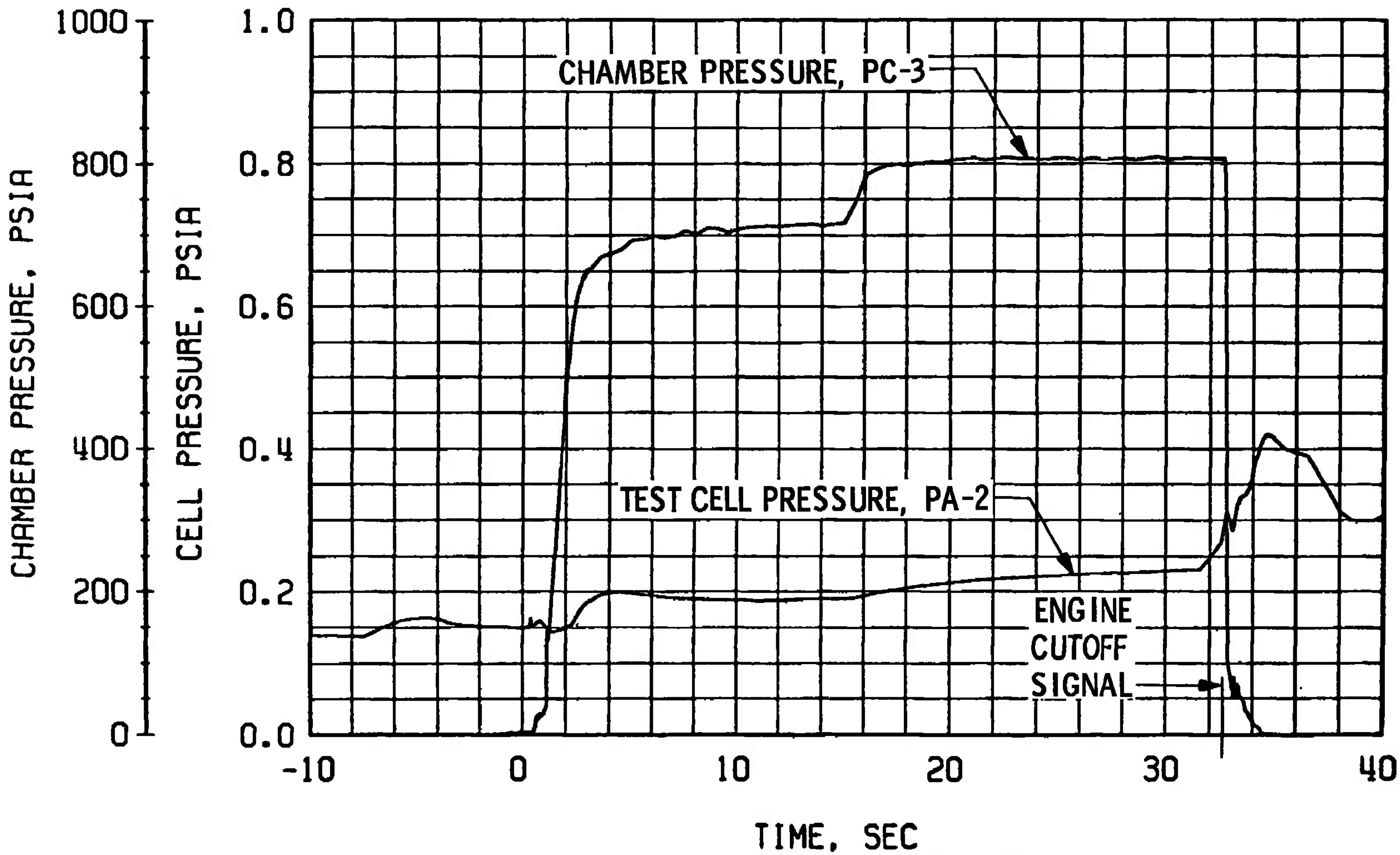
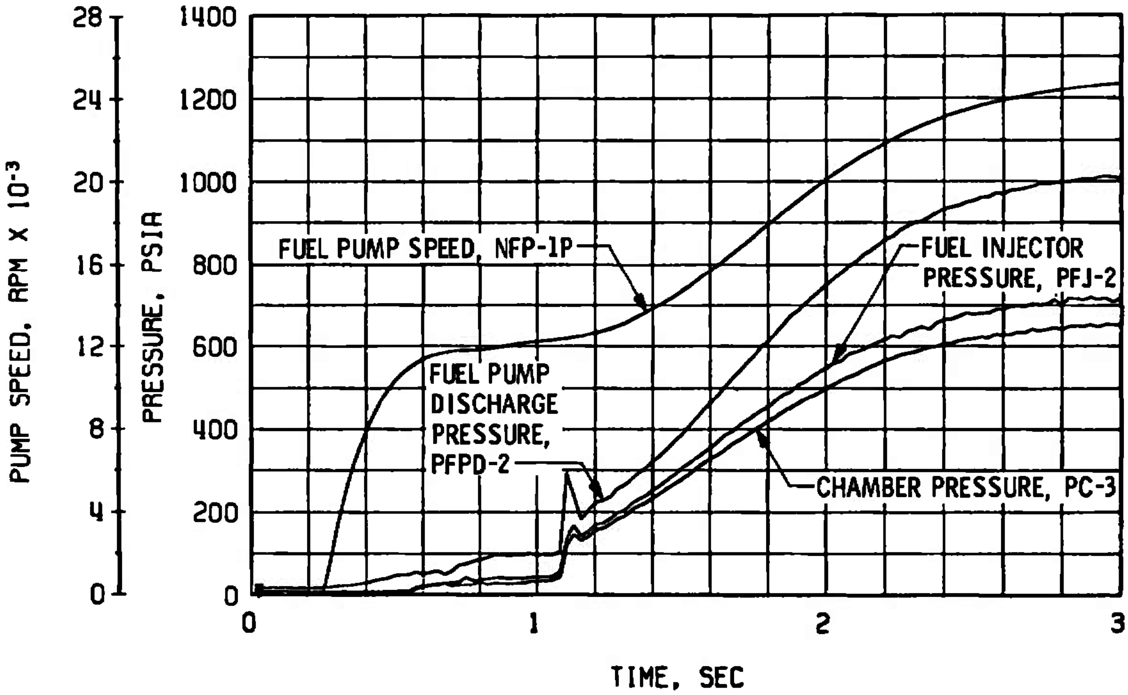
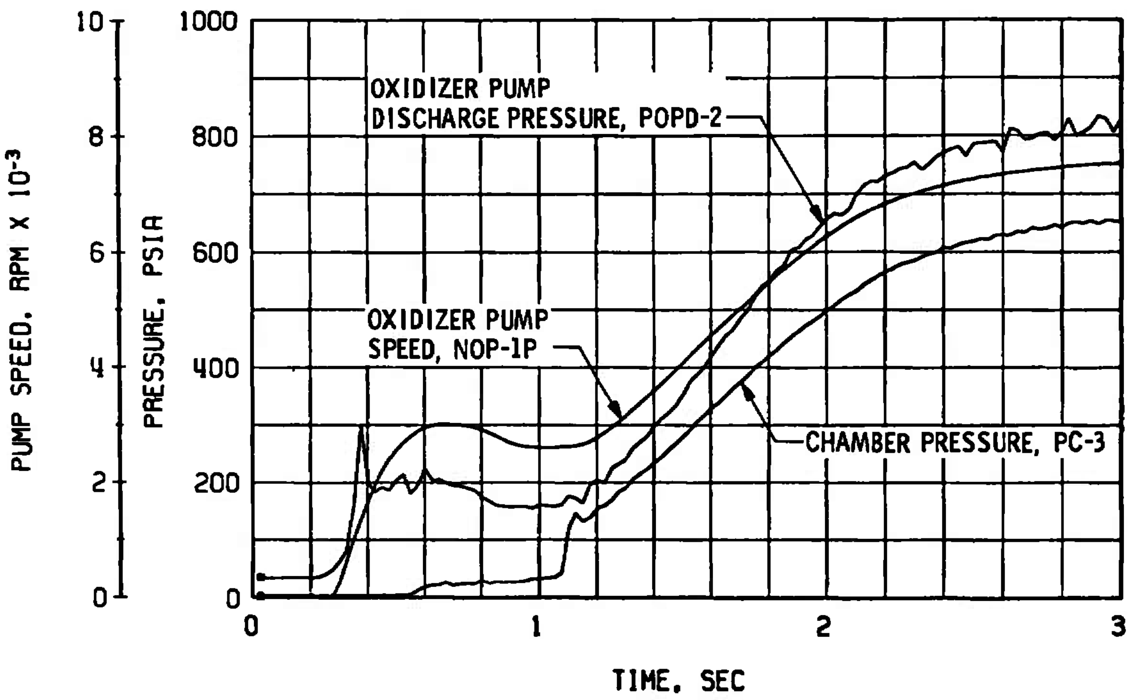


Fig. 56 Engine Ambient and Combustion Chamber Pressures, Firing 31B

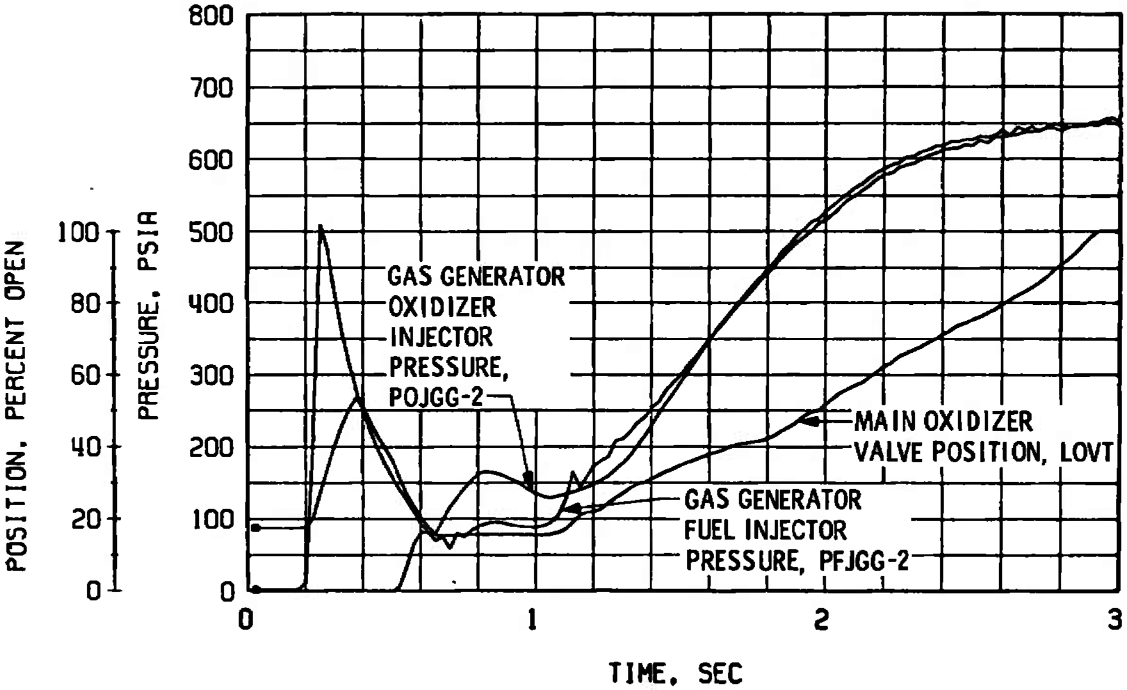


a. Thrust Chamber Fuel System, Start

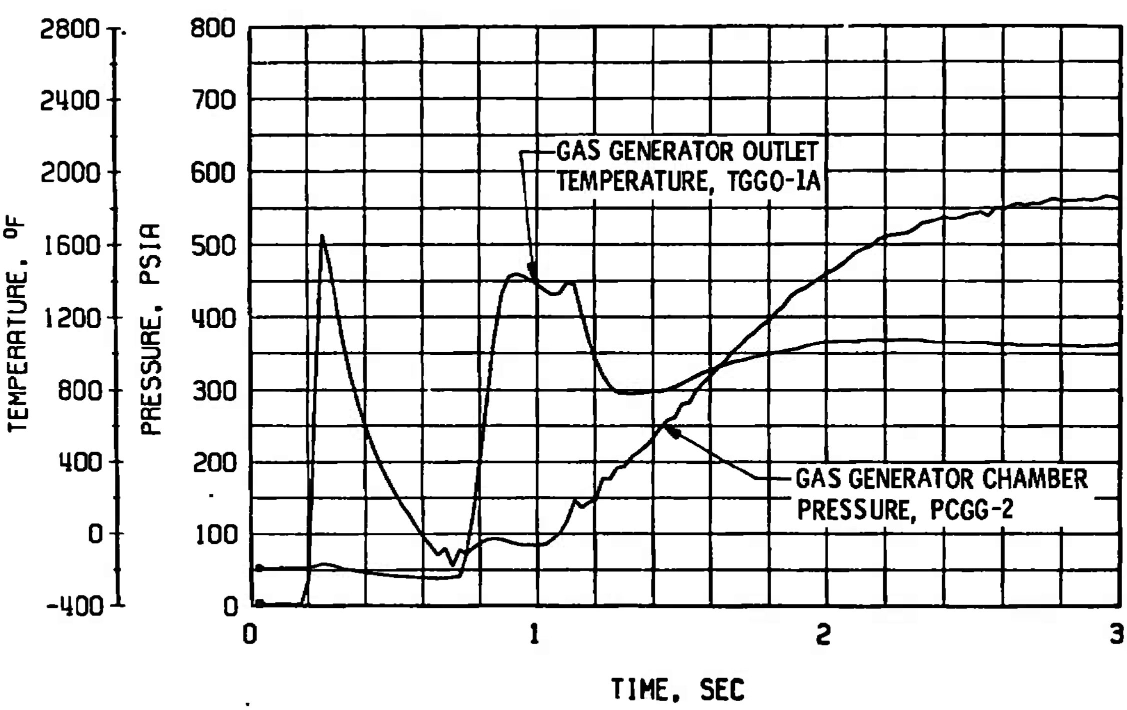


b. Thrust Chamber Oxidizer System, Start

Fig. 57 Engine Transient Operation, Firing 31B

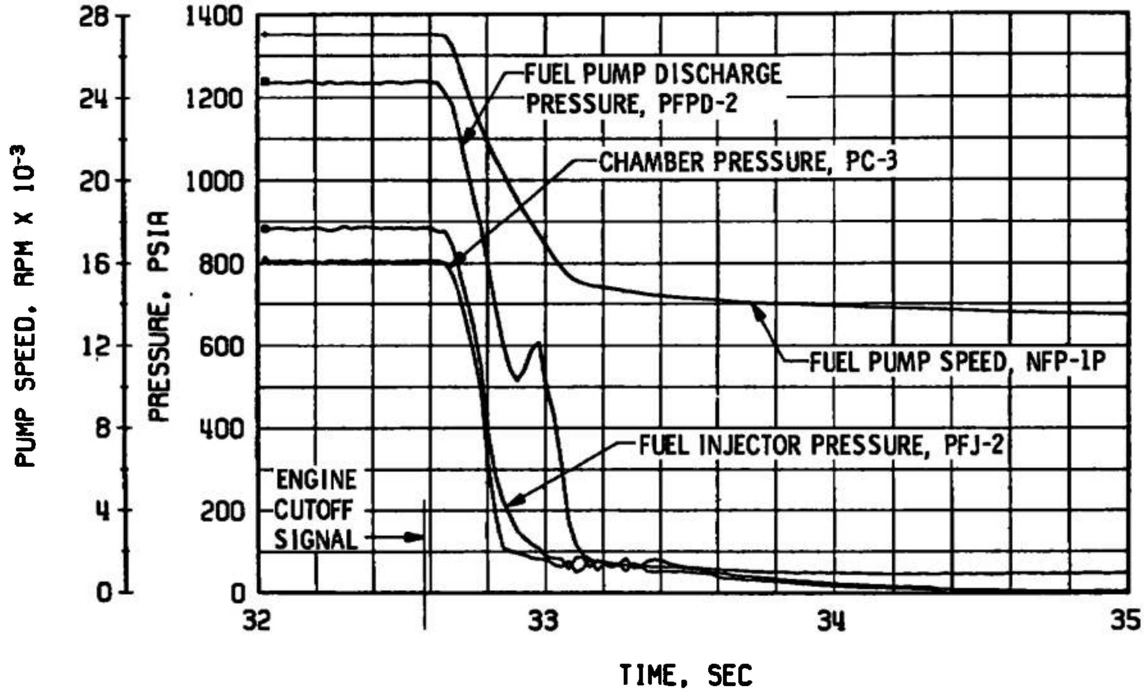


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

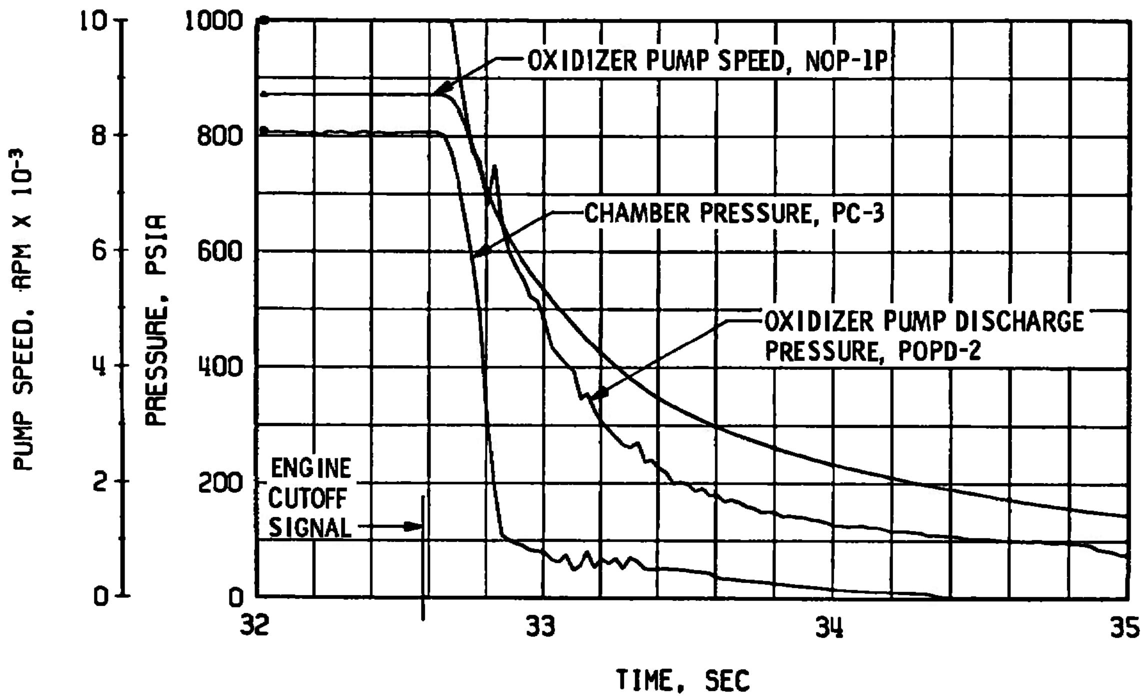


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 57 Continued

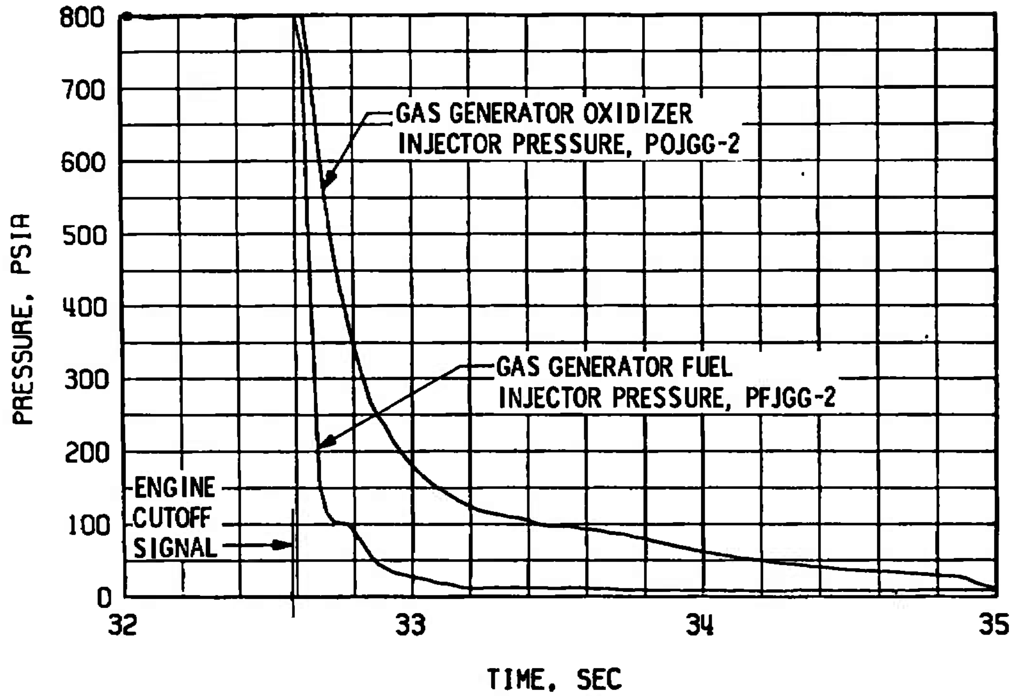


e. Thrust Chamber Fuel System, Shutdown

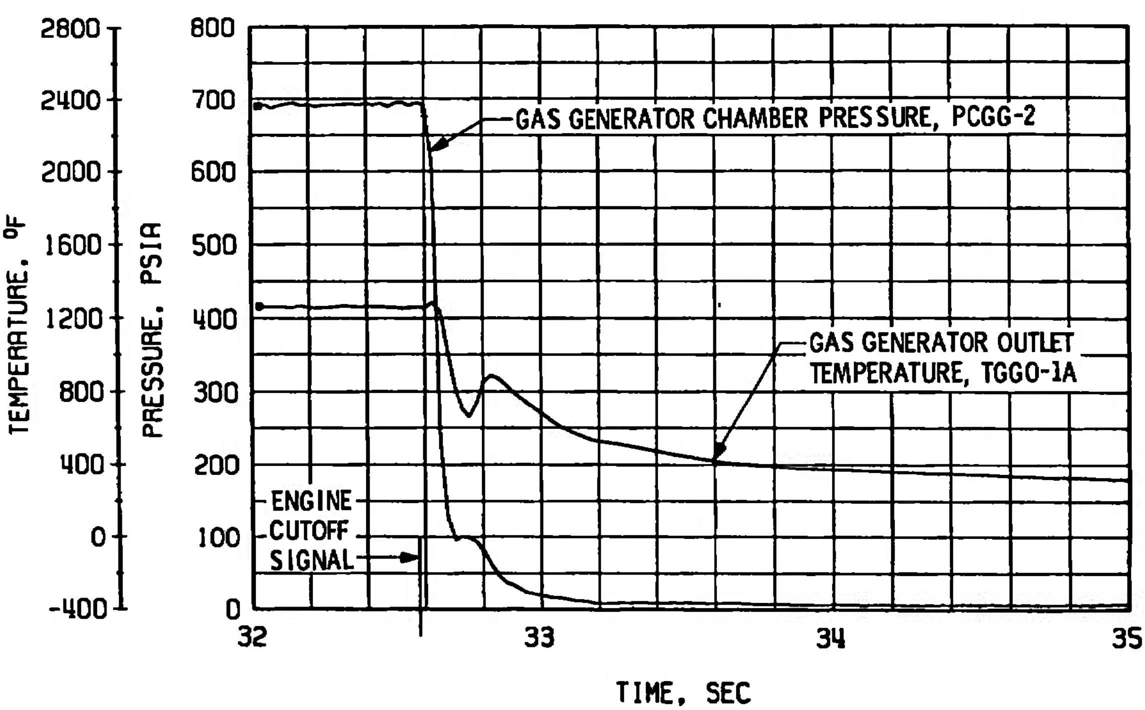


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 57 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 57 Concluded

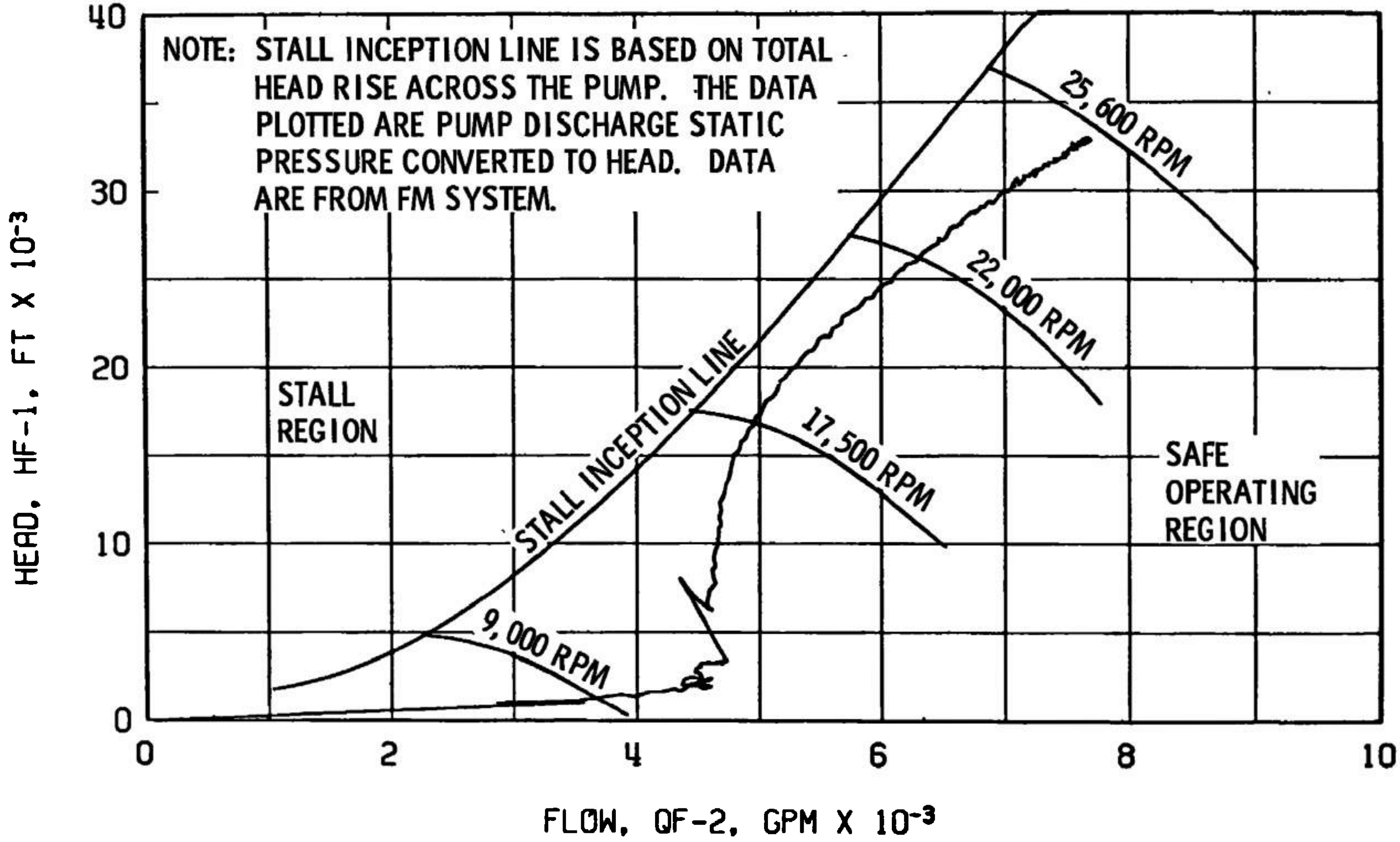
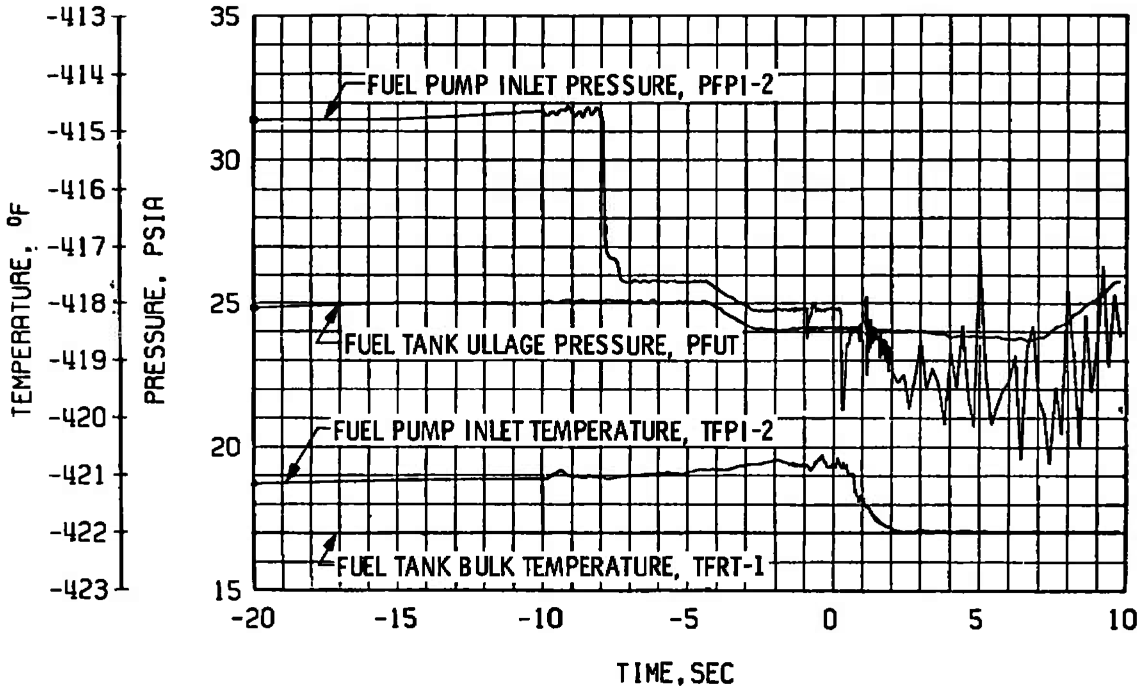
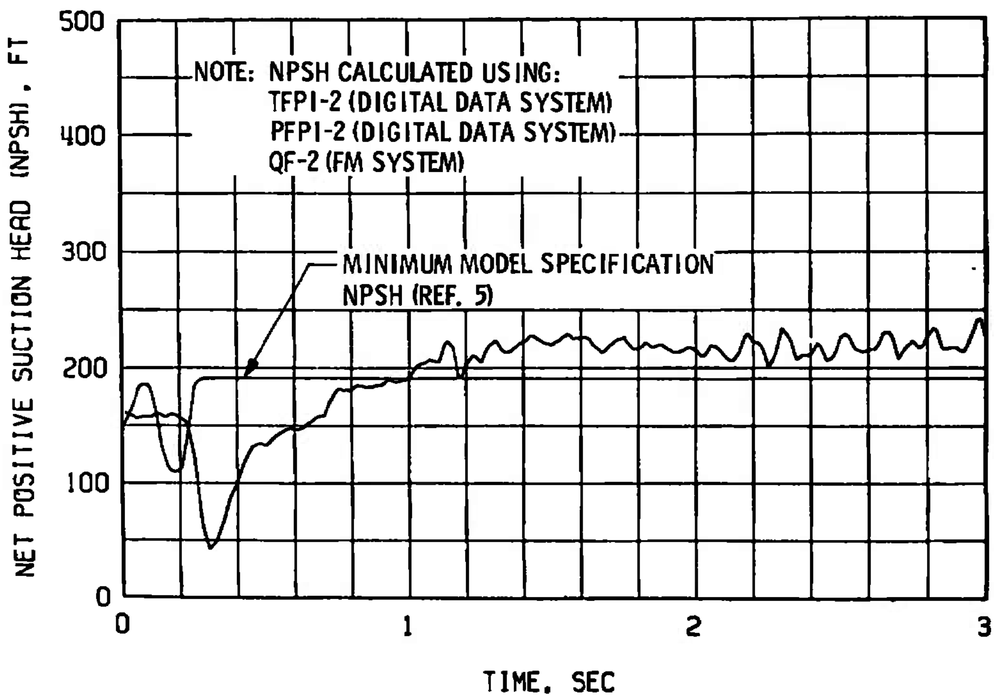


Fig. 58 Fuel Pump Start Transient Performance, Firing 31B

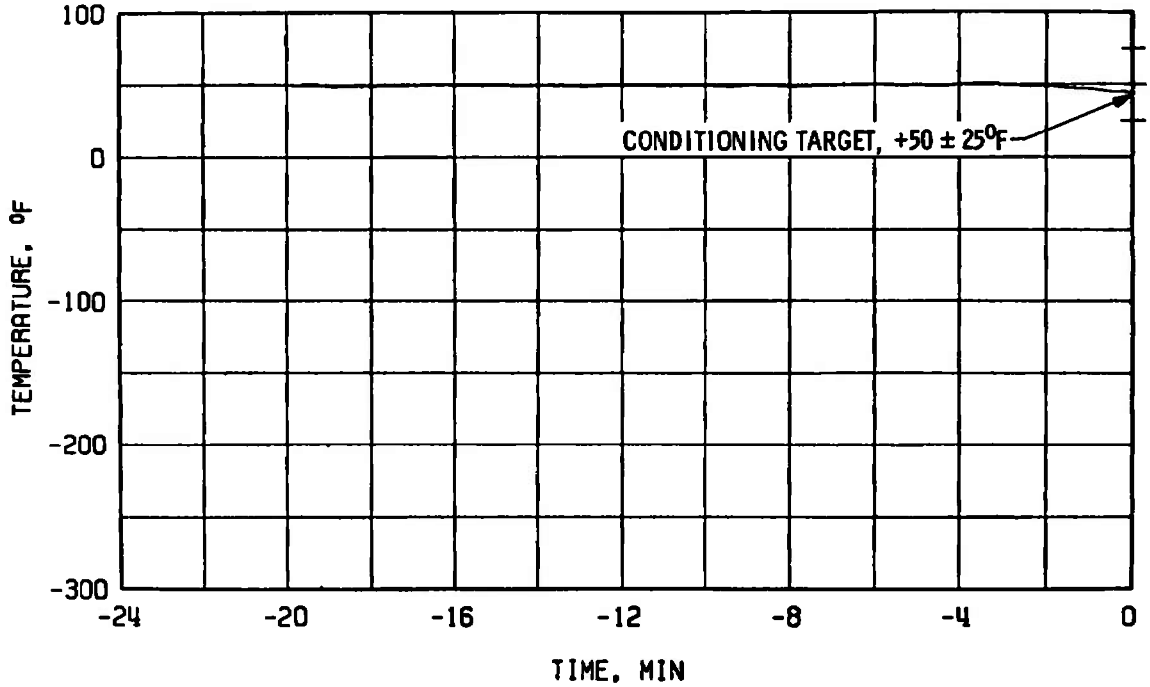


a. Duct Pressure and Temperature Transients

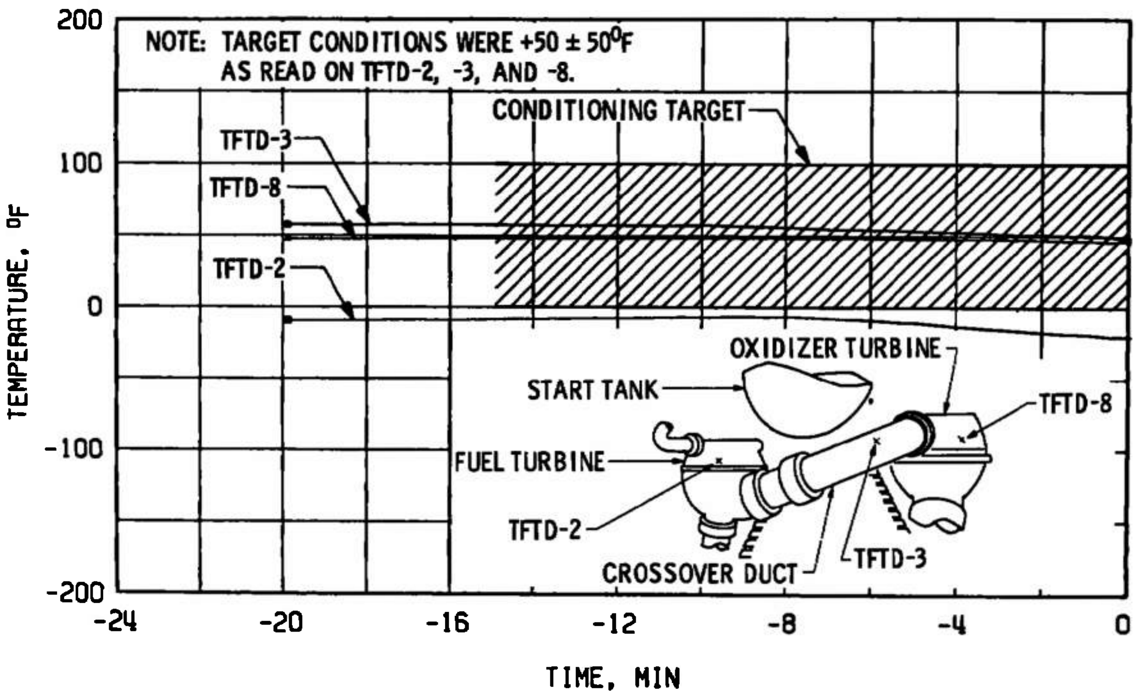


b. Fuel Pump NPSH during Start Transient, Firing 31B

Fig. 59 Fuel Low Pressure Duct Performance, Firing 31B

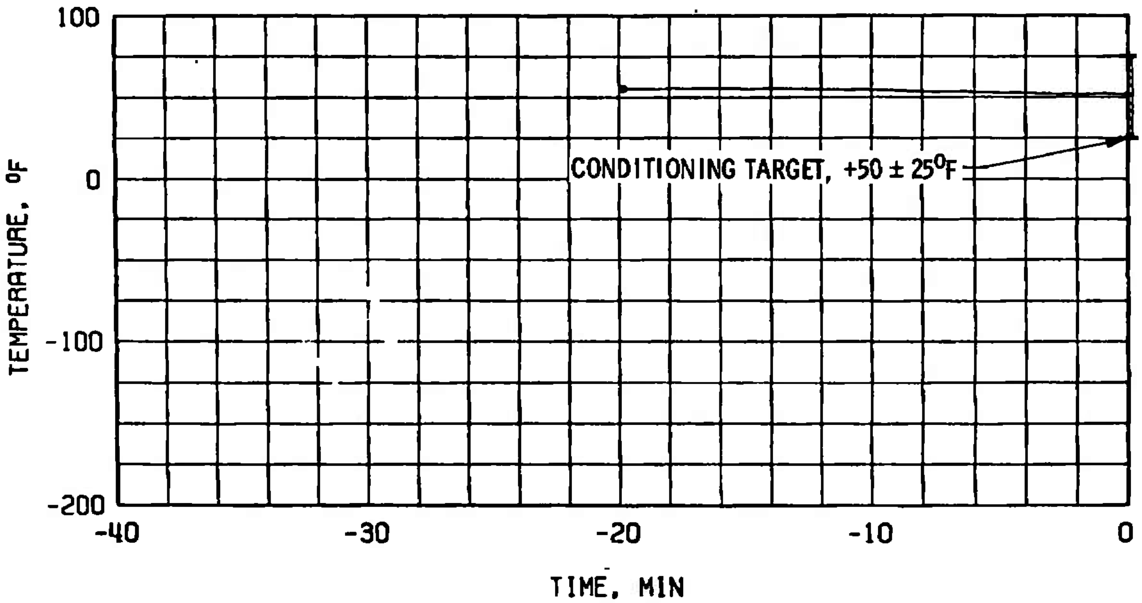


a. Thrust Chamber Throat, TTC-1P

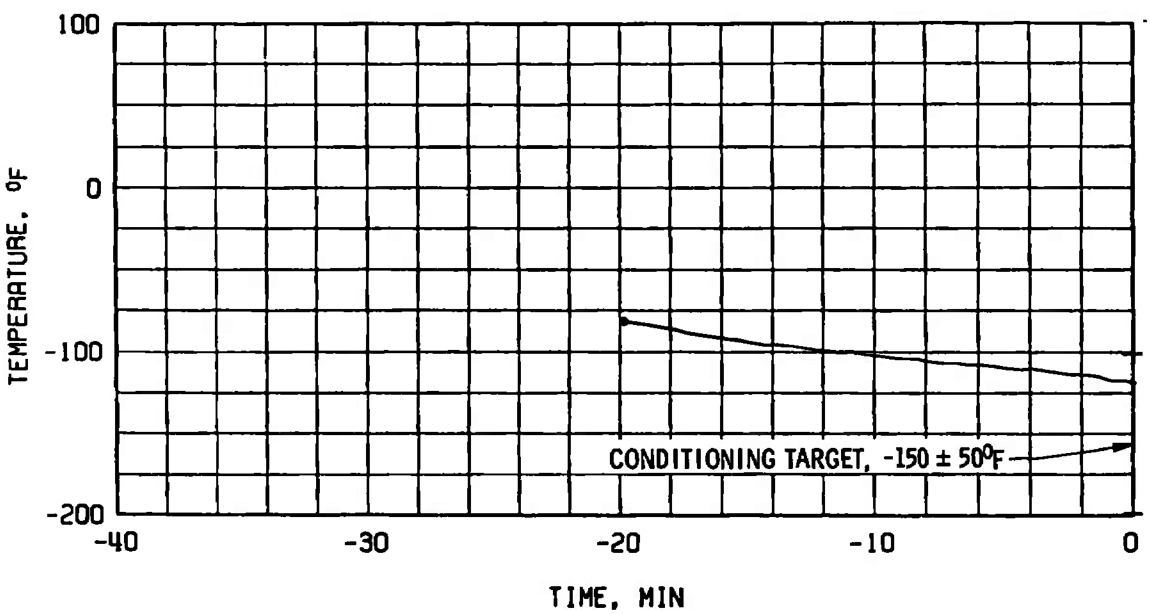


b. Crossover Duct, TFTD

Fig. 60 Thermal Conditioning History of Engine Components, Firing 31C



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 60 Concluded

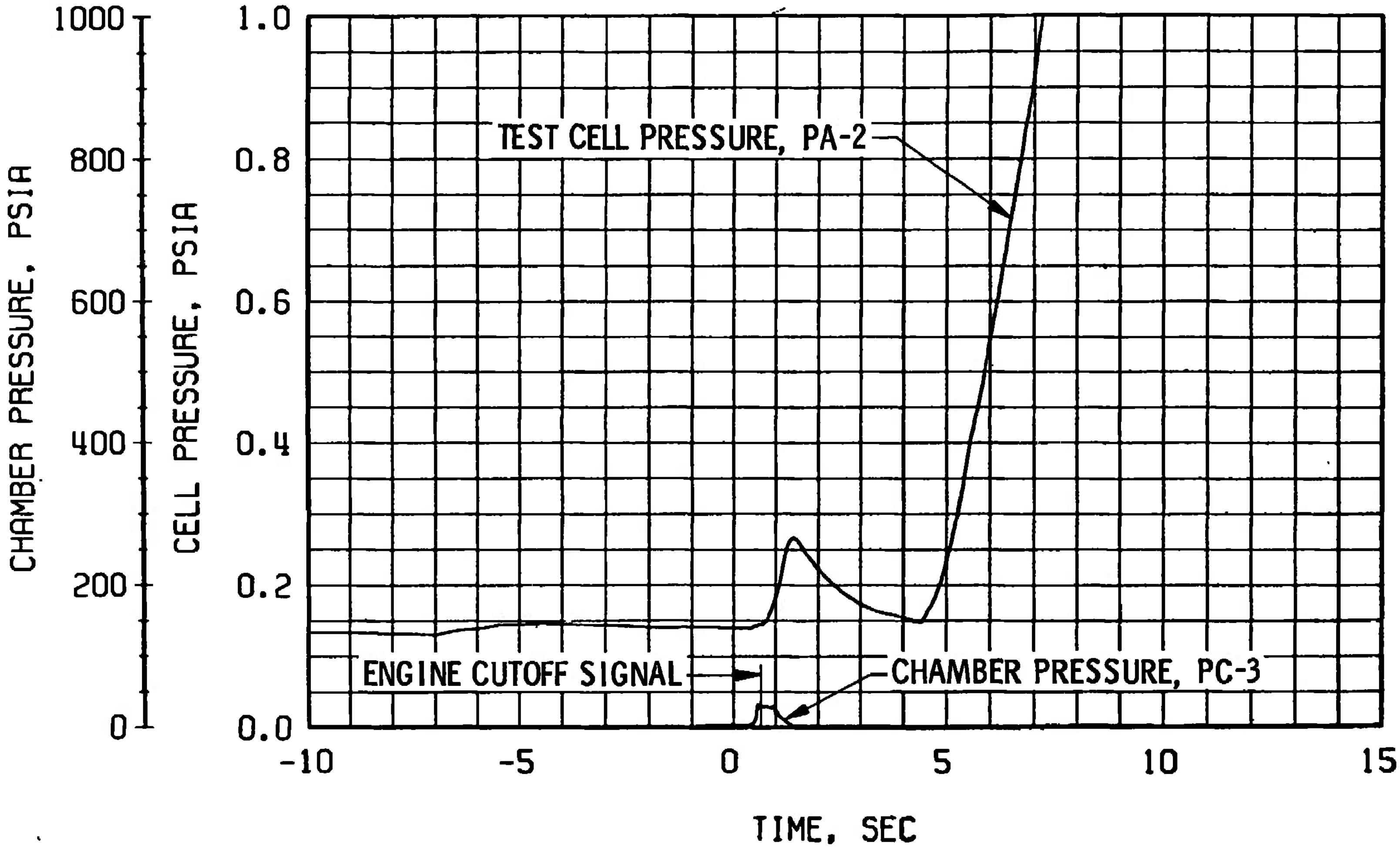
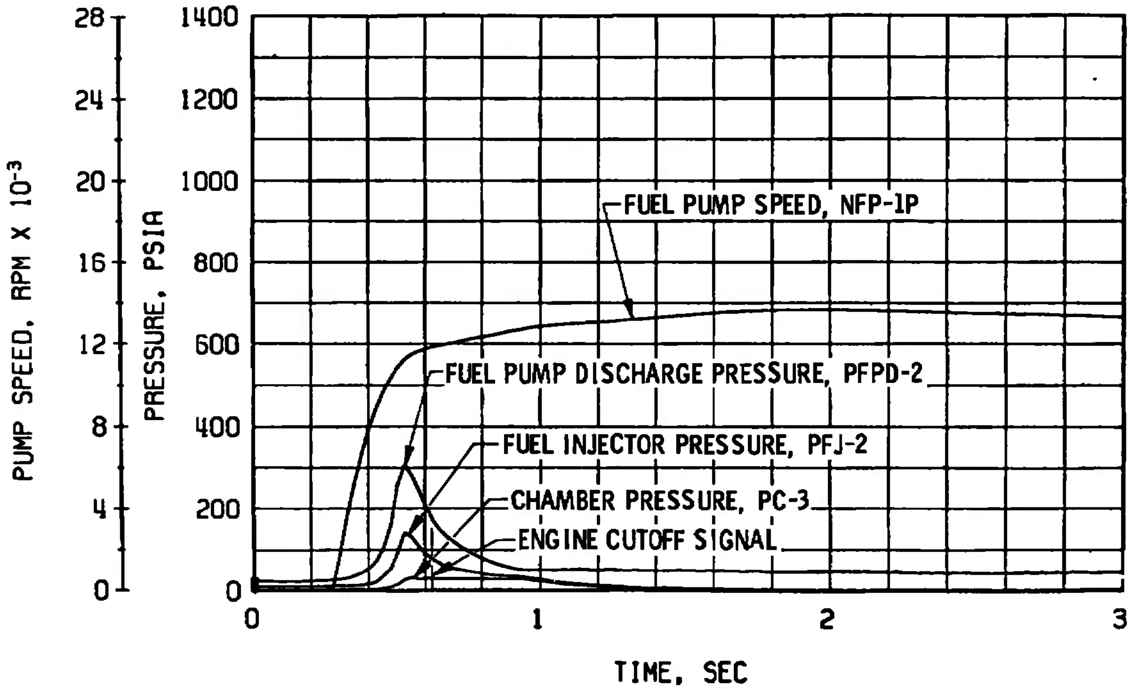
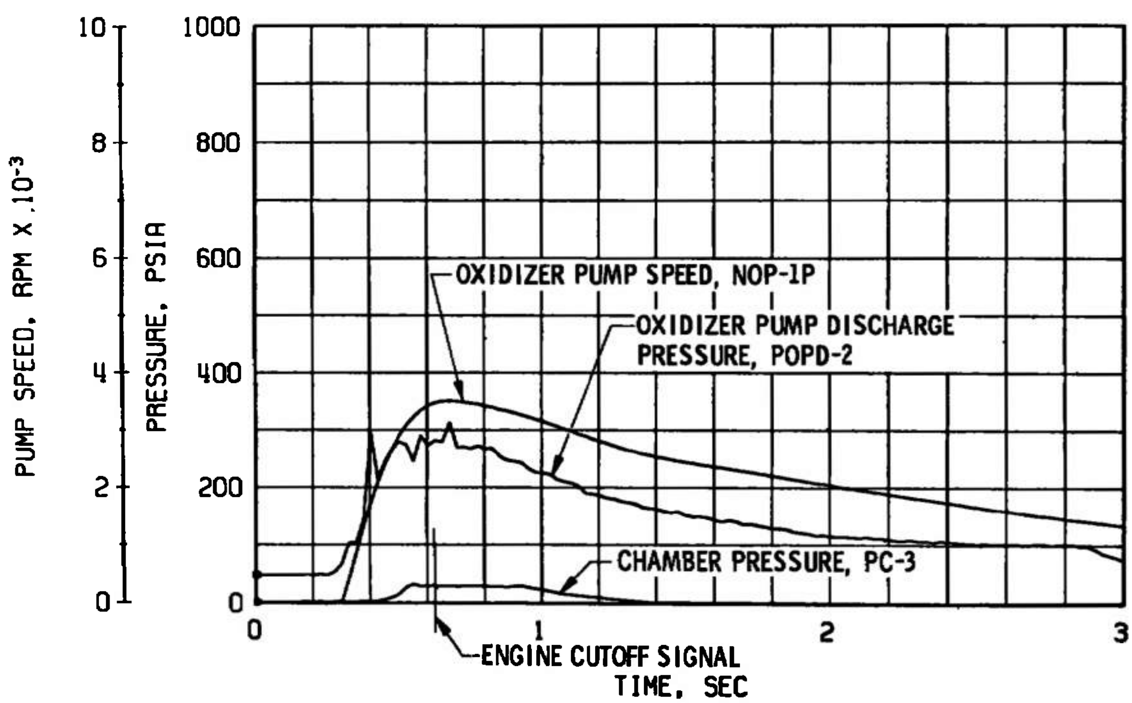


Fig. 61 Engine Ambient and Combustion Chamber Pressures, Firing 31C

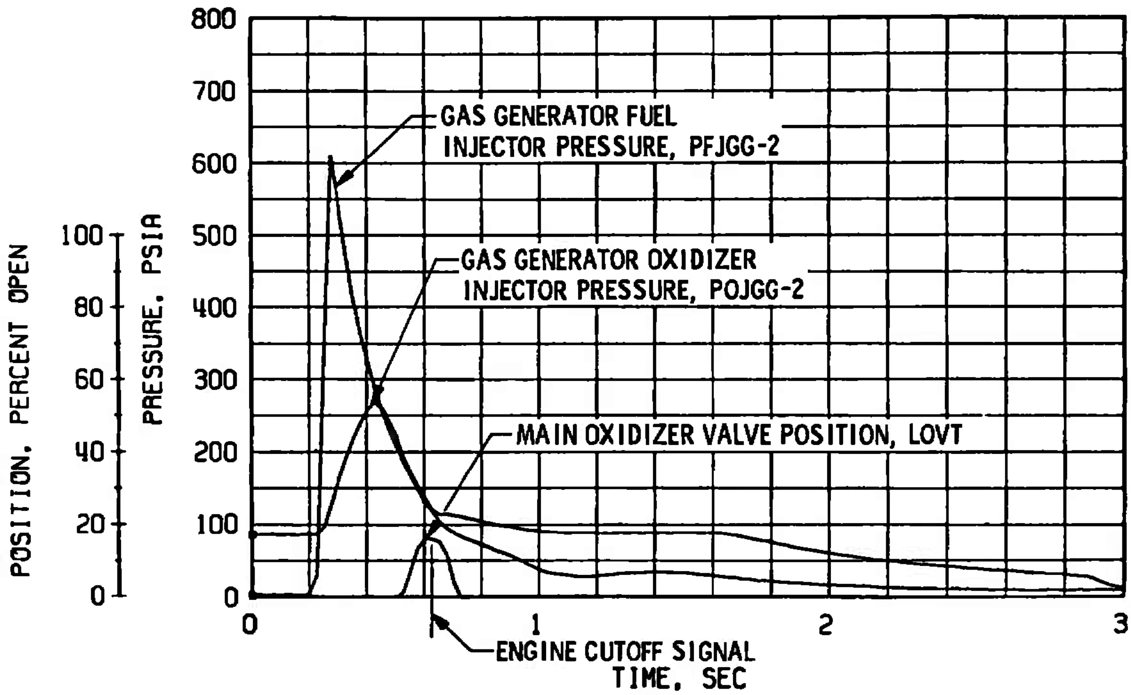


a. Thrust Chamber Fuel System, Start and Shutdown

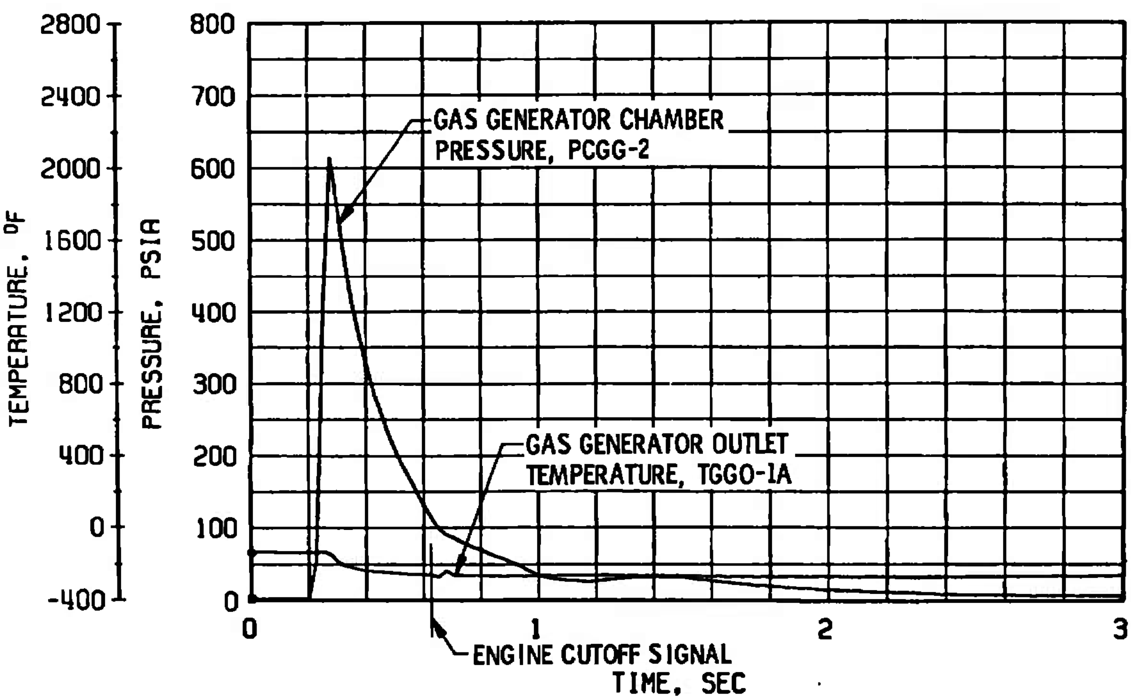


b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 62 Engine Transient Operation, Firing 31C



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Pressure and Temperature, Start and Shutdown

Fig. 62 Concluded

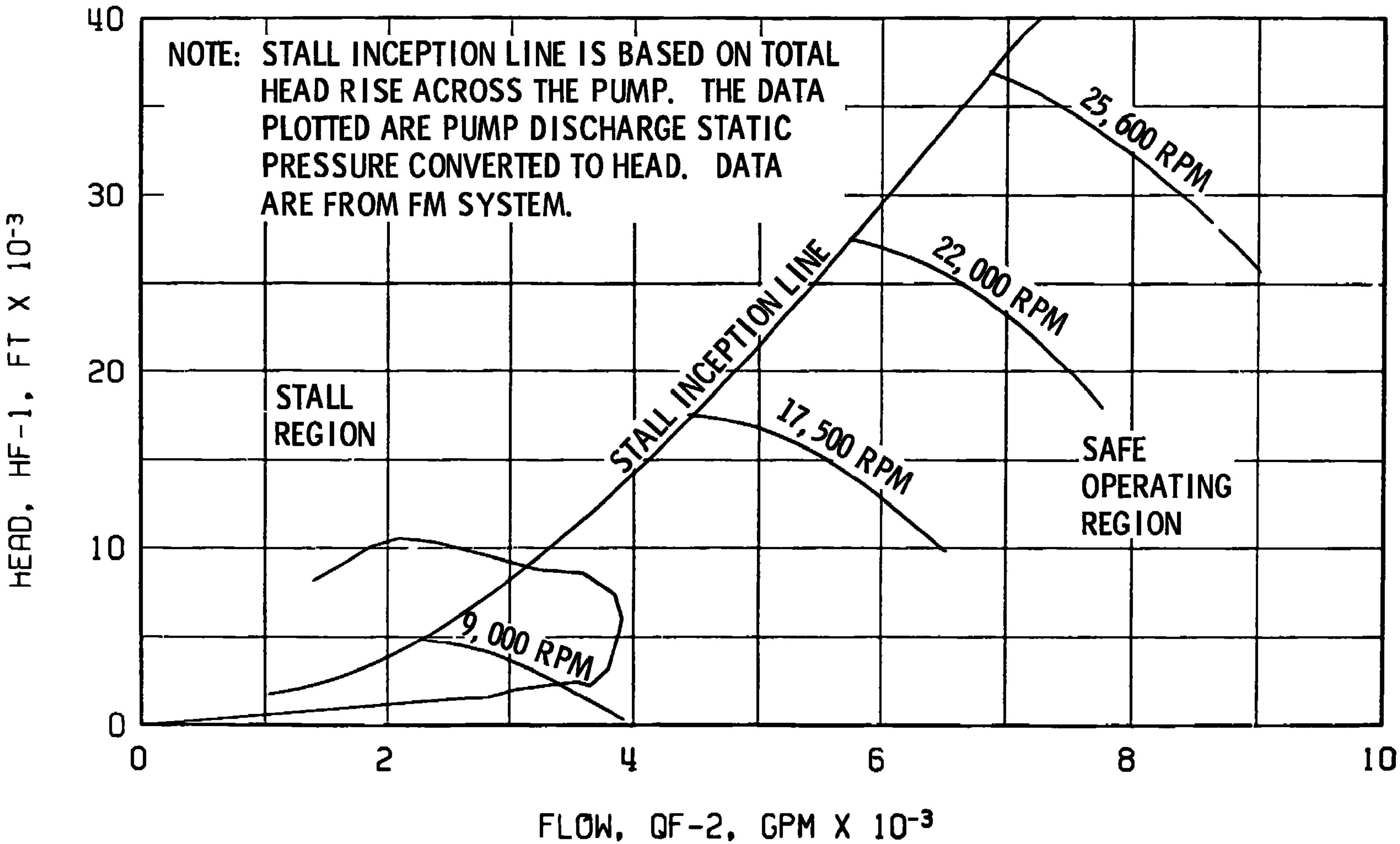
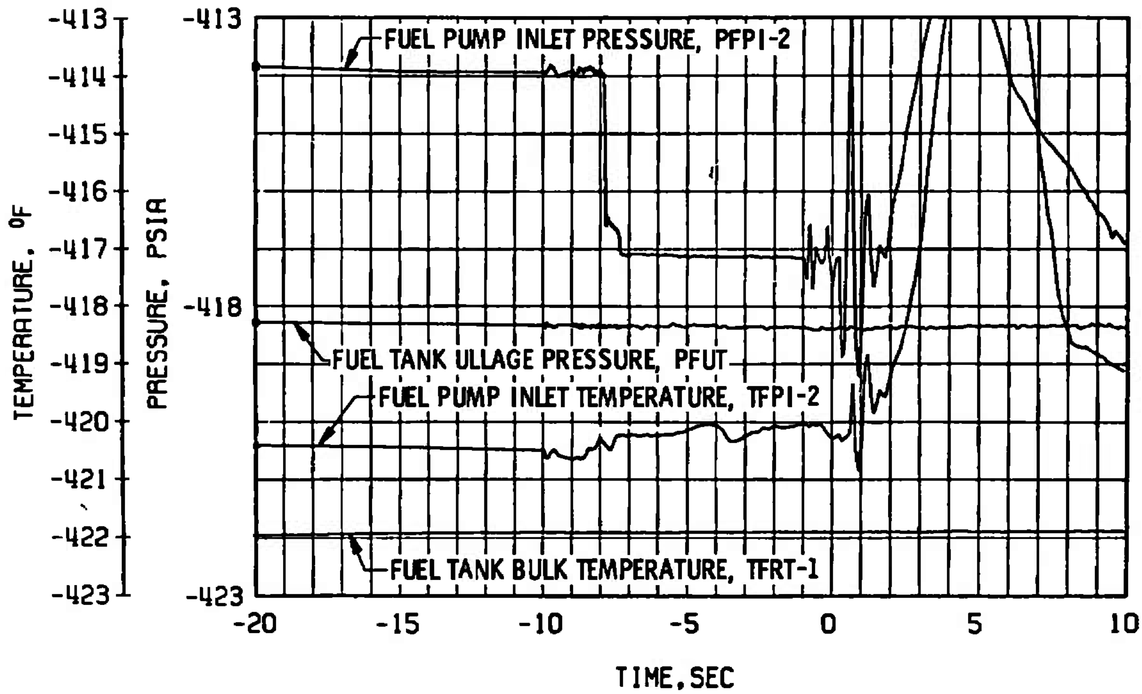
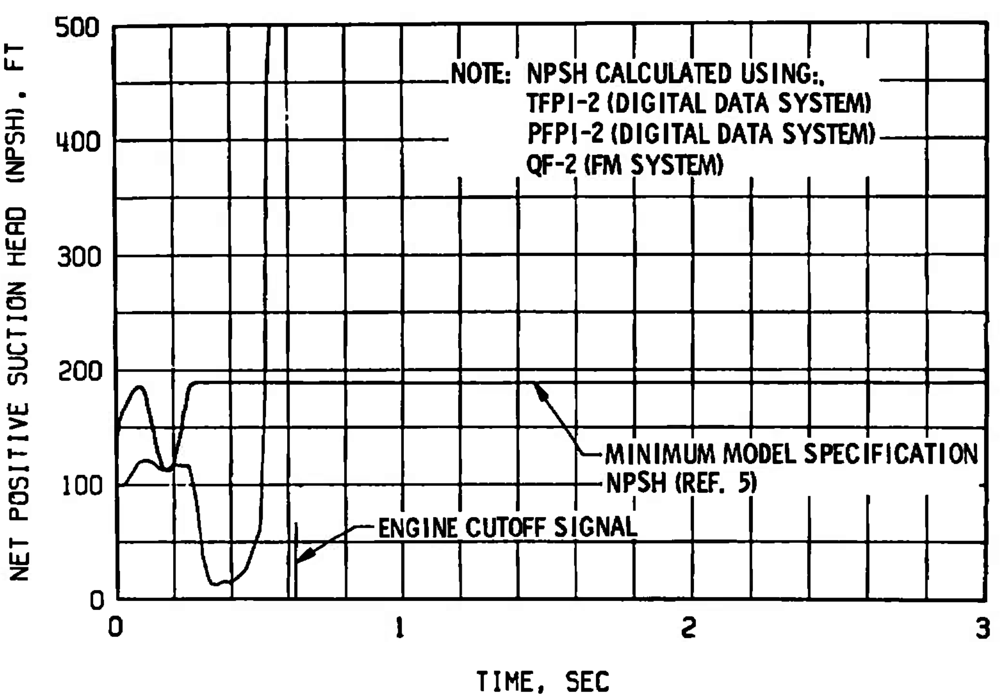


Fig. 63 Fuel Pump Start Transient Performance, Firing 31C

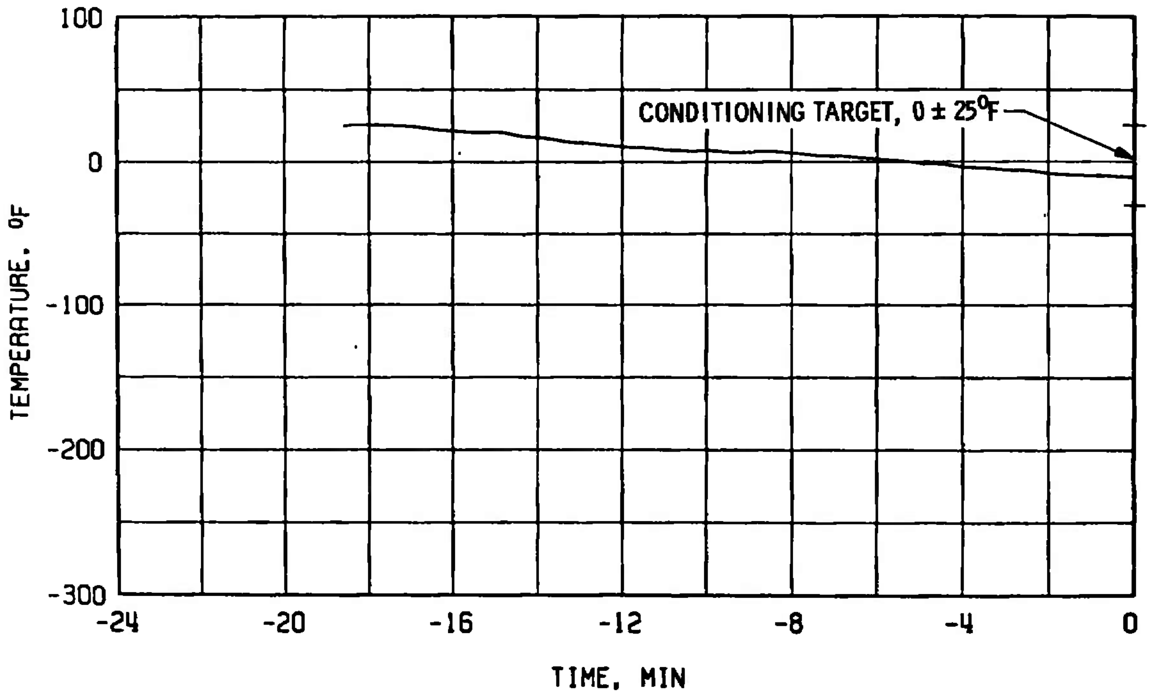


a. Duct Pressure and Temperature Transients

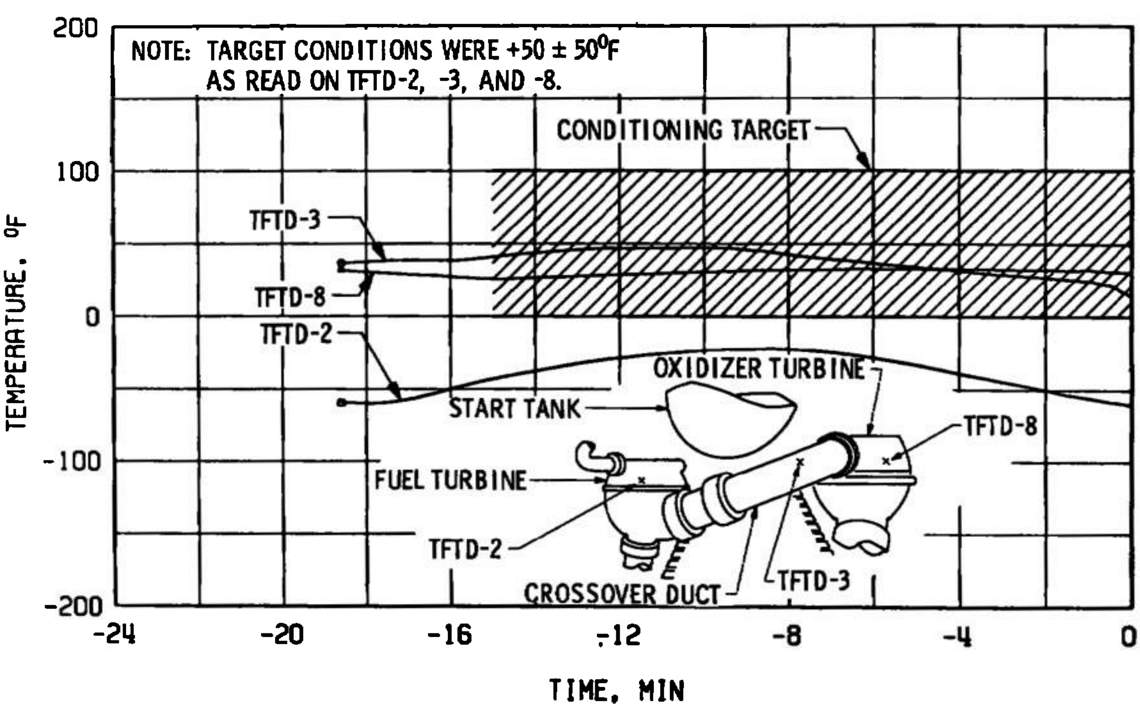


b. Fuel Pump NPSH during Start Transients, Firing 31C

Fig. 64 Fuel Low Pressure Duct Performance, Firing 31C

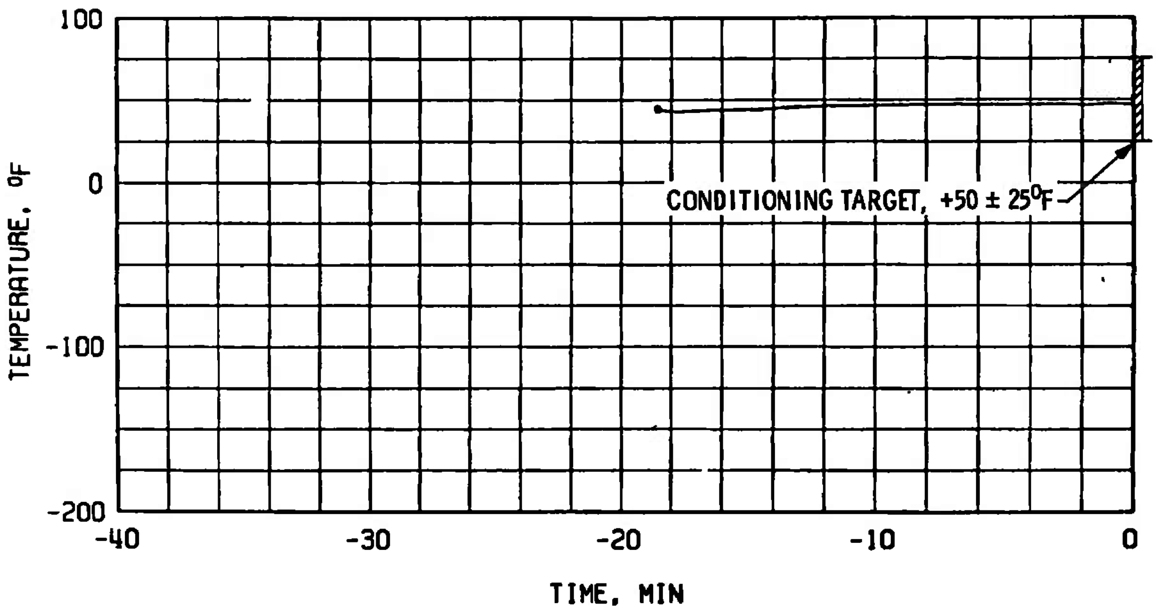


a. Thrust Chamber Throat, TTC-1P

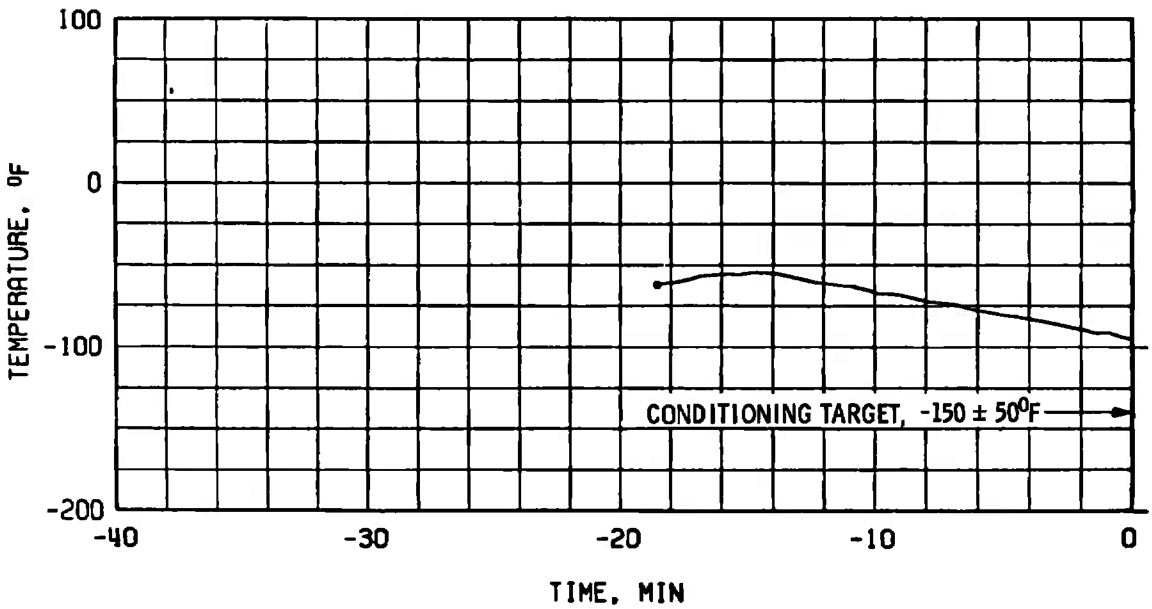


b. Crossover Duct, TFTD

Fig. 65 Thermal Conditioning History of Engine Components, Firing 31D



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 65 Concluded

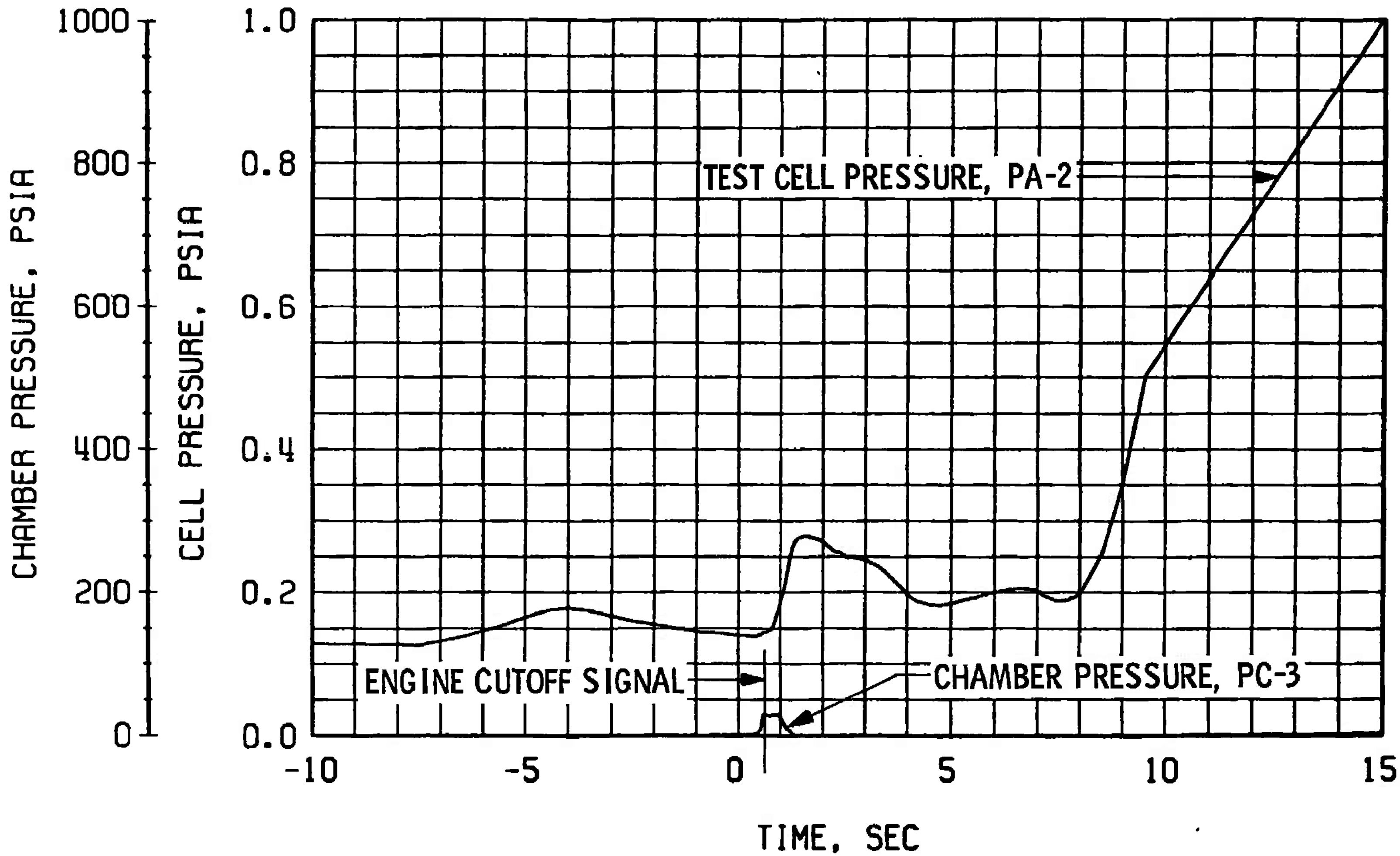
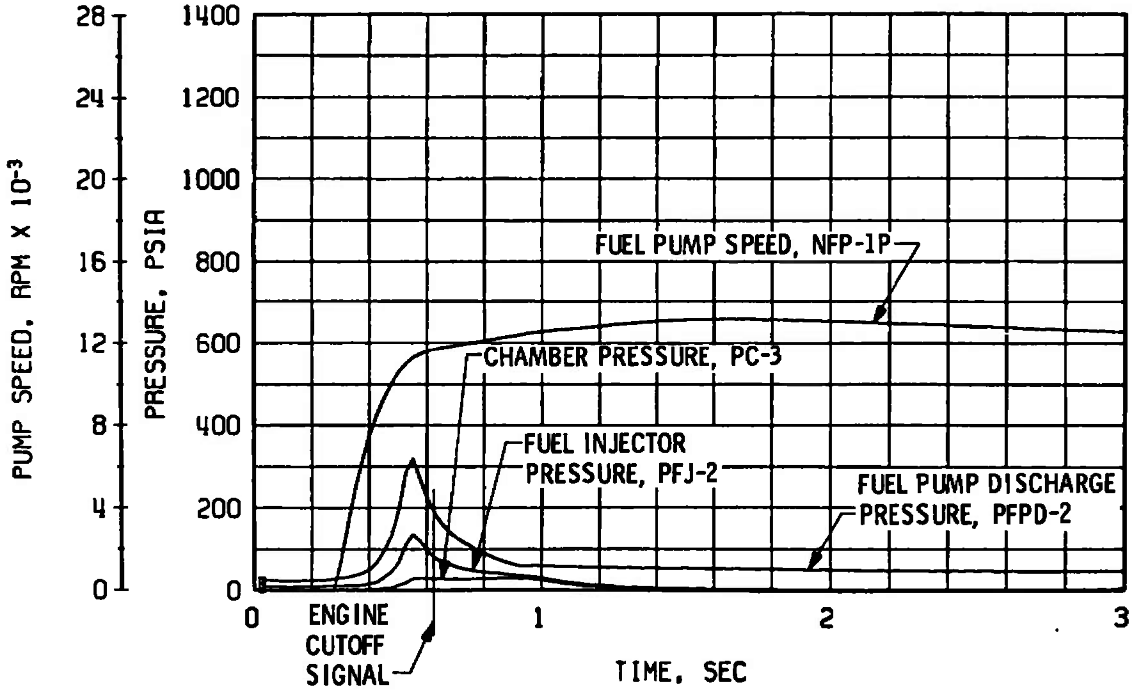
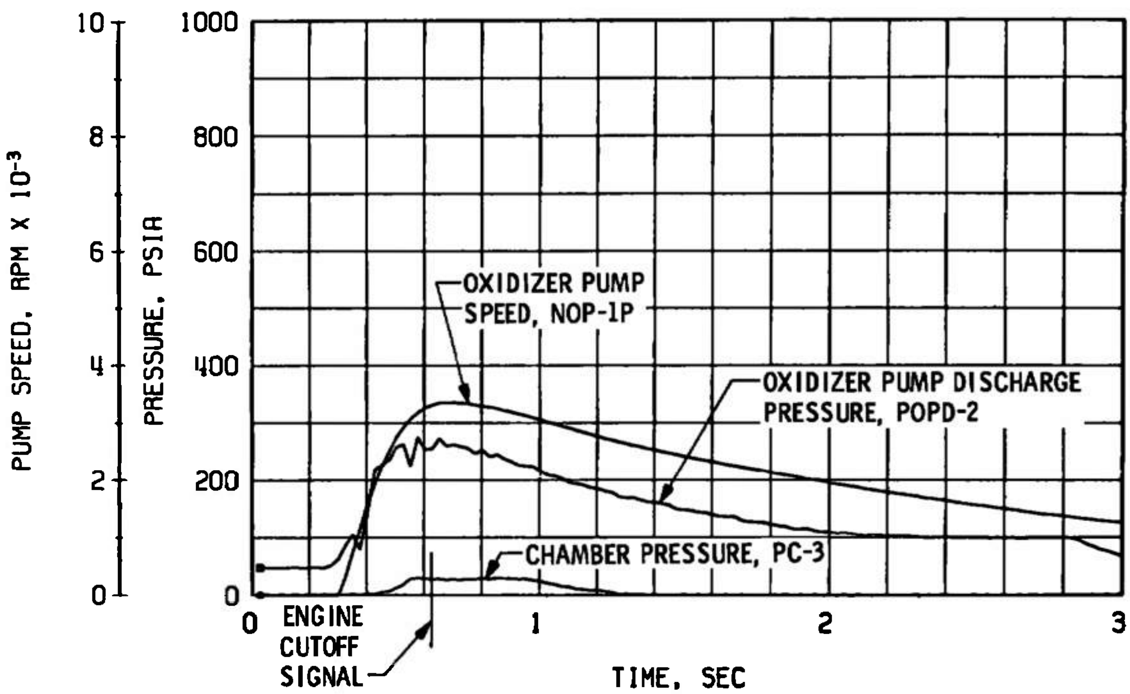


Fig. 66 Engine Ambient and Combustion Chamber Pressures, Firing 31D

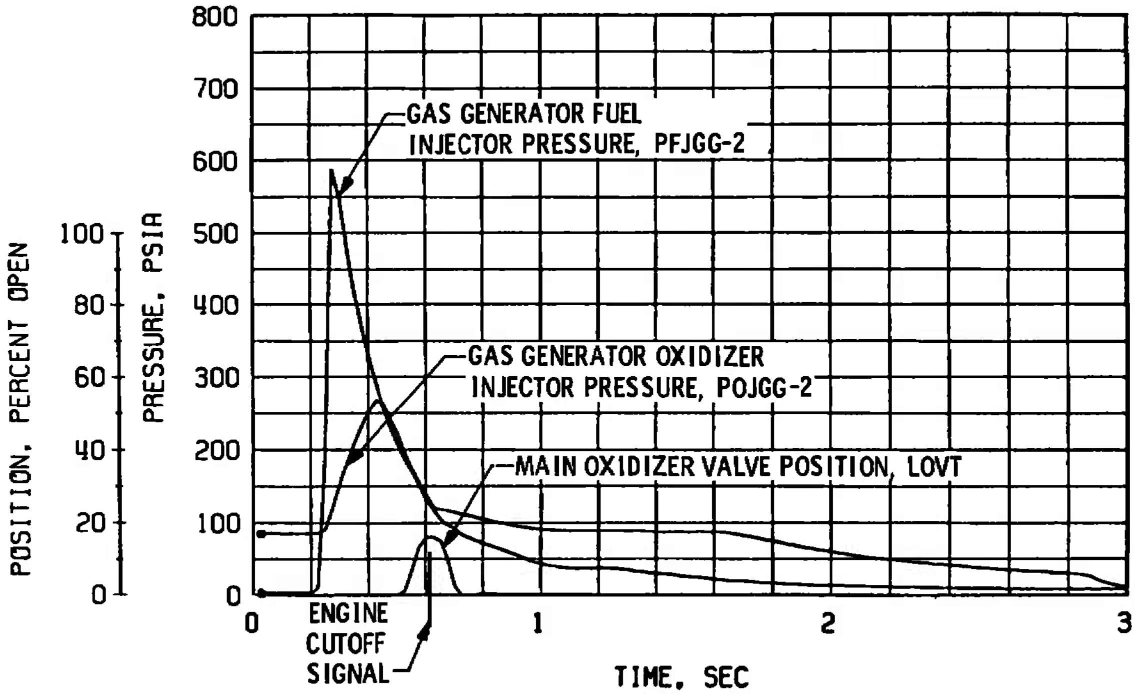


a. Thrust Chamber Fuel System, Start and Shutdown

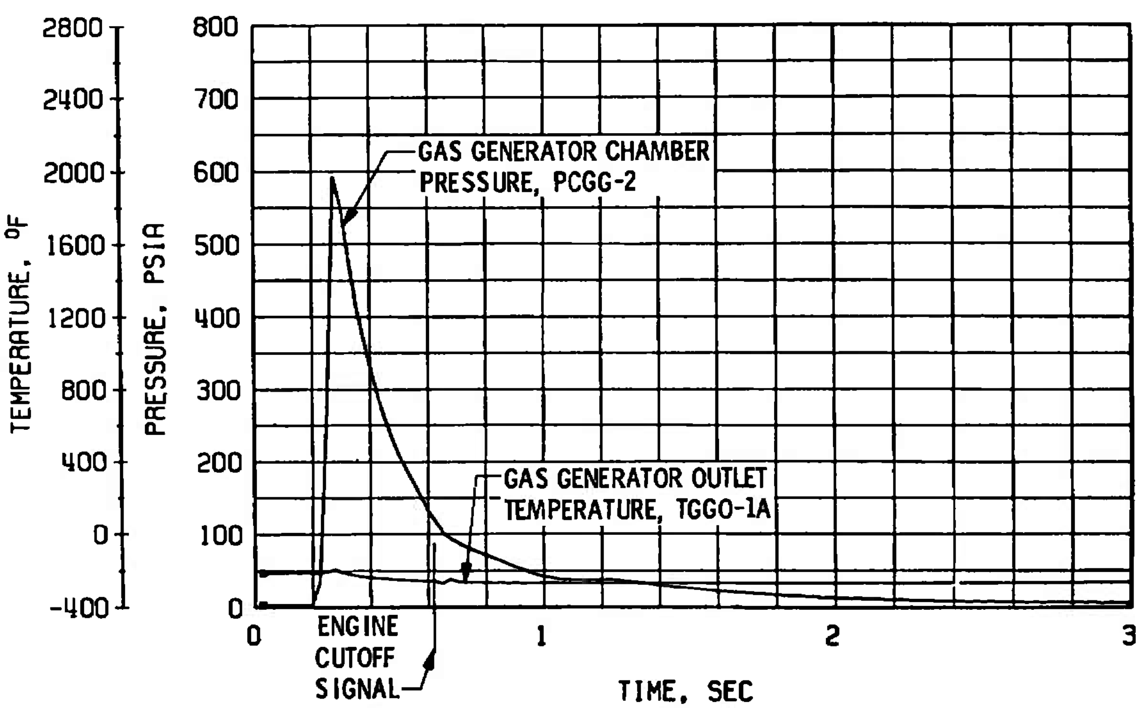


b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 67 Engine Transient Operation, Firing 31D



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 67 Concluded

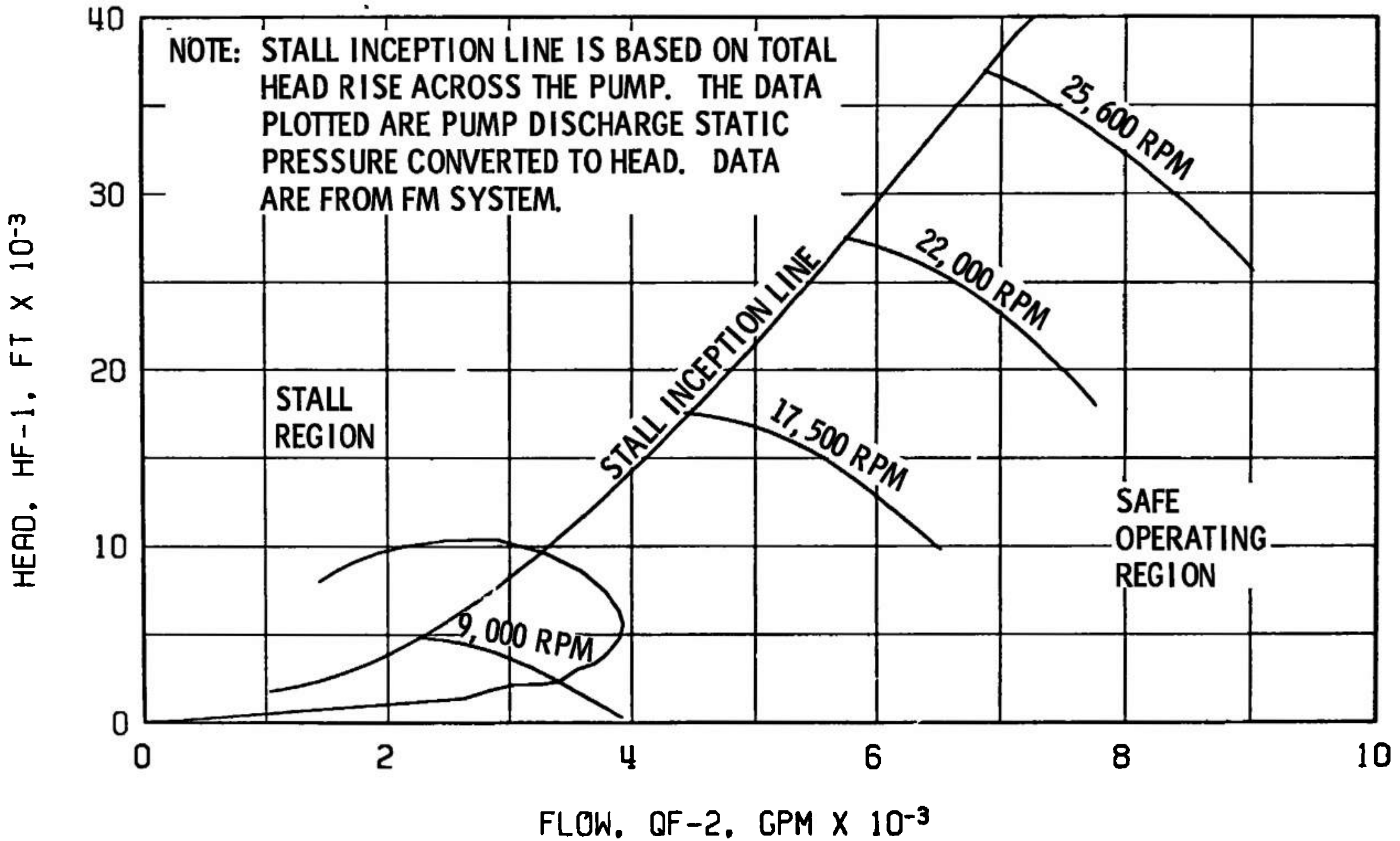
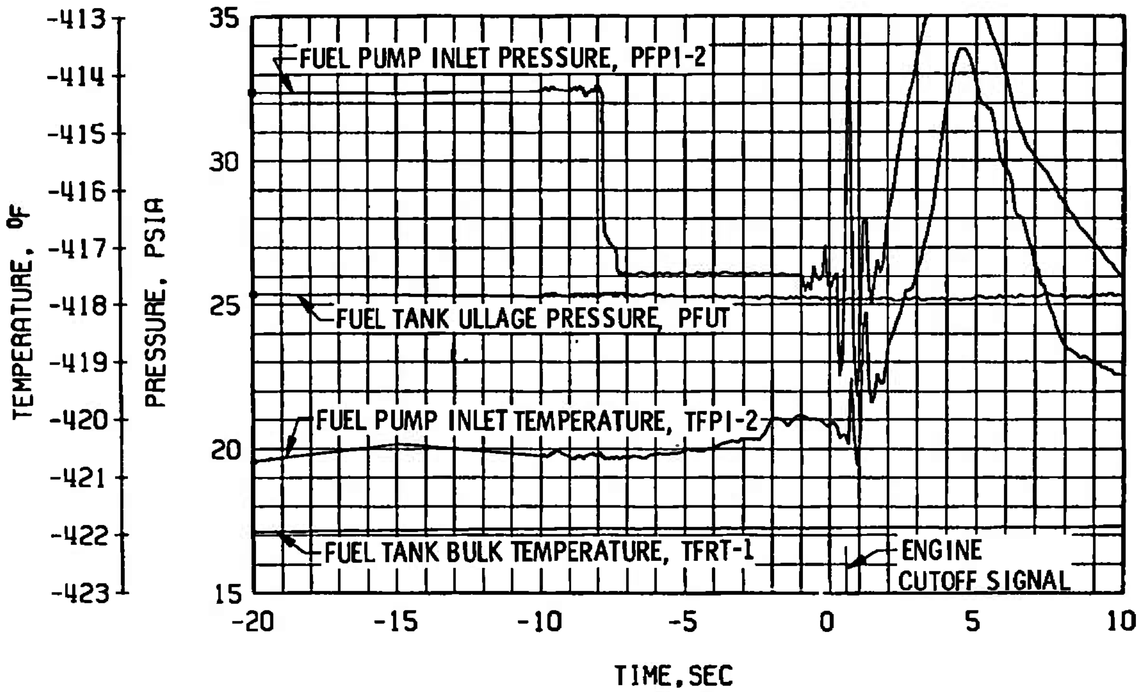
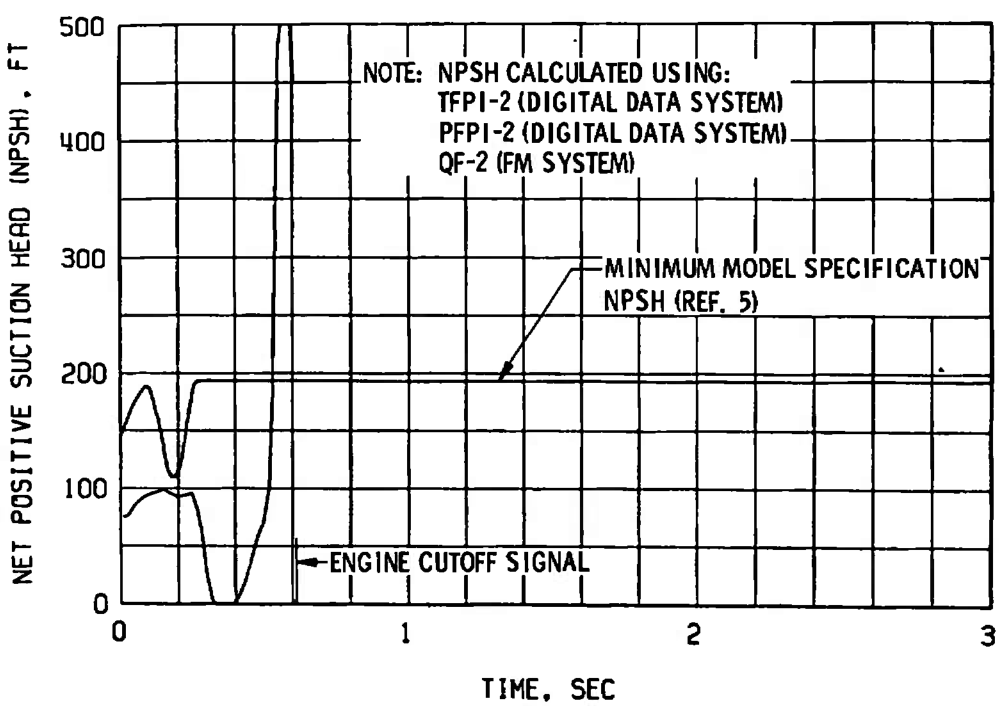


Fig. 68 Fuel Pump Start Transient Performance, Firing 31D

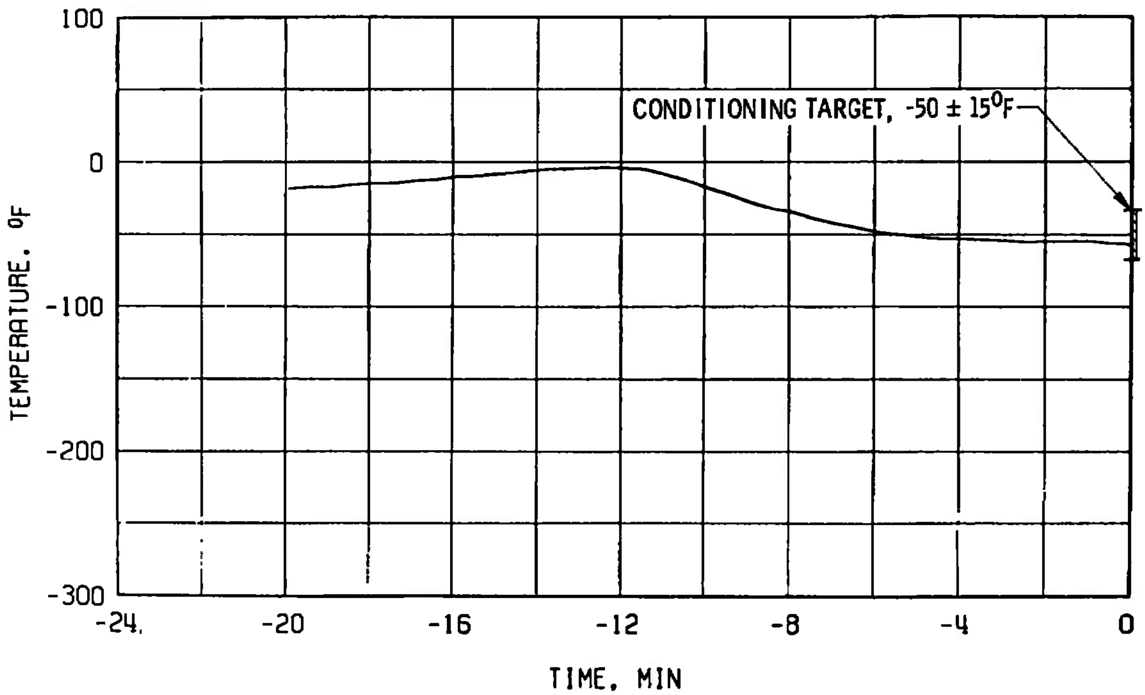


a. Duct Pressure and Temperature Transients

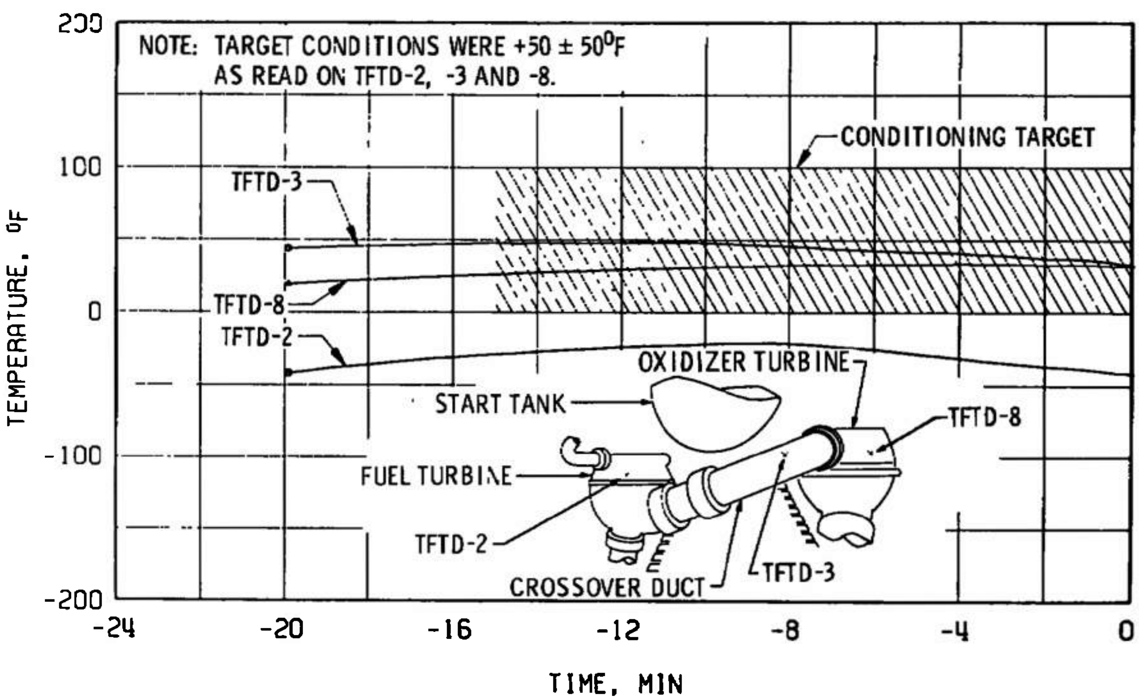


b. Fuel Pump NPSH during Start Transient, Firing 31D

Fig. 69 Fuel Low Pressure Duct Performance, Firing 31D

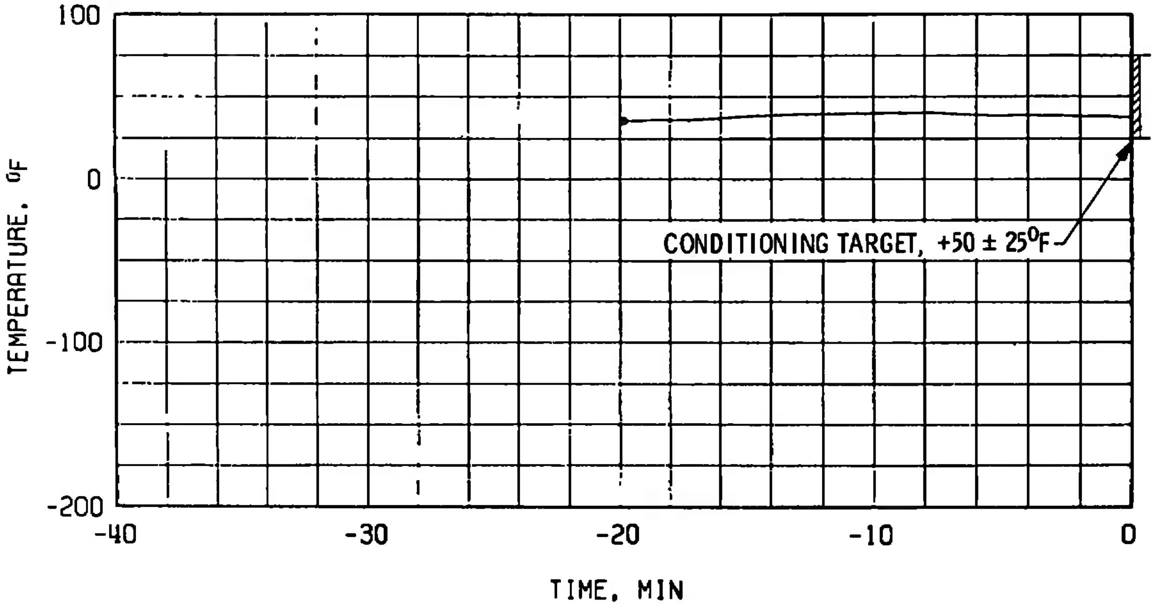


a. Thrust Chamber Throat, TTC-1P

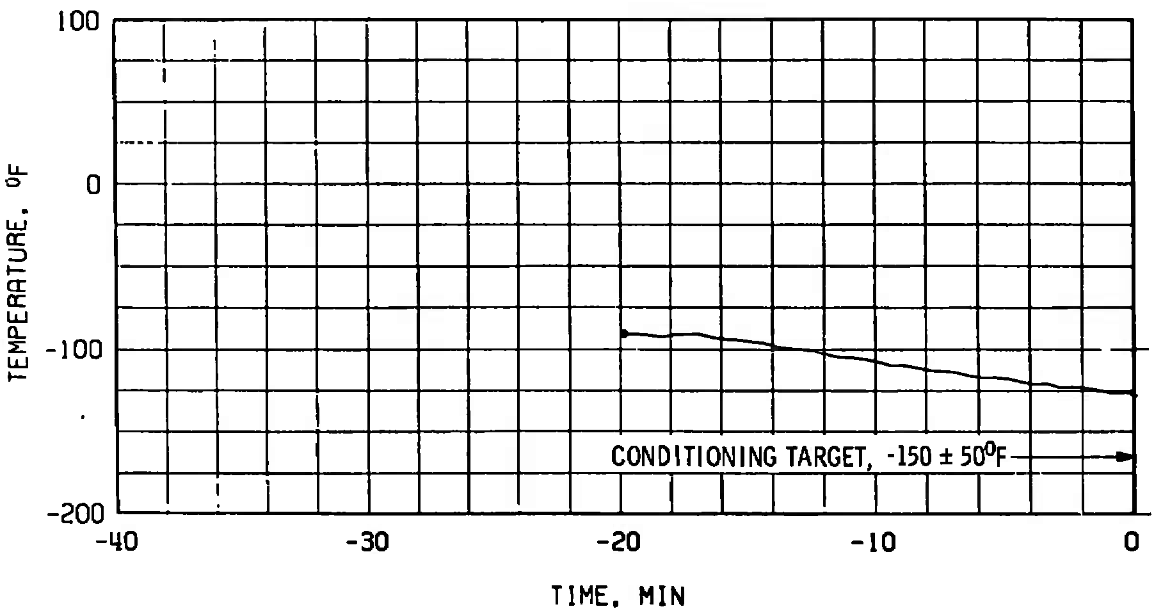


b. Crossover Duct, TFTD

Fig. 70 Thermal Conditioning History of Engine Components, Firing 31E



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 70 Concluded

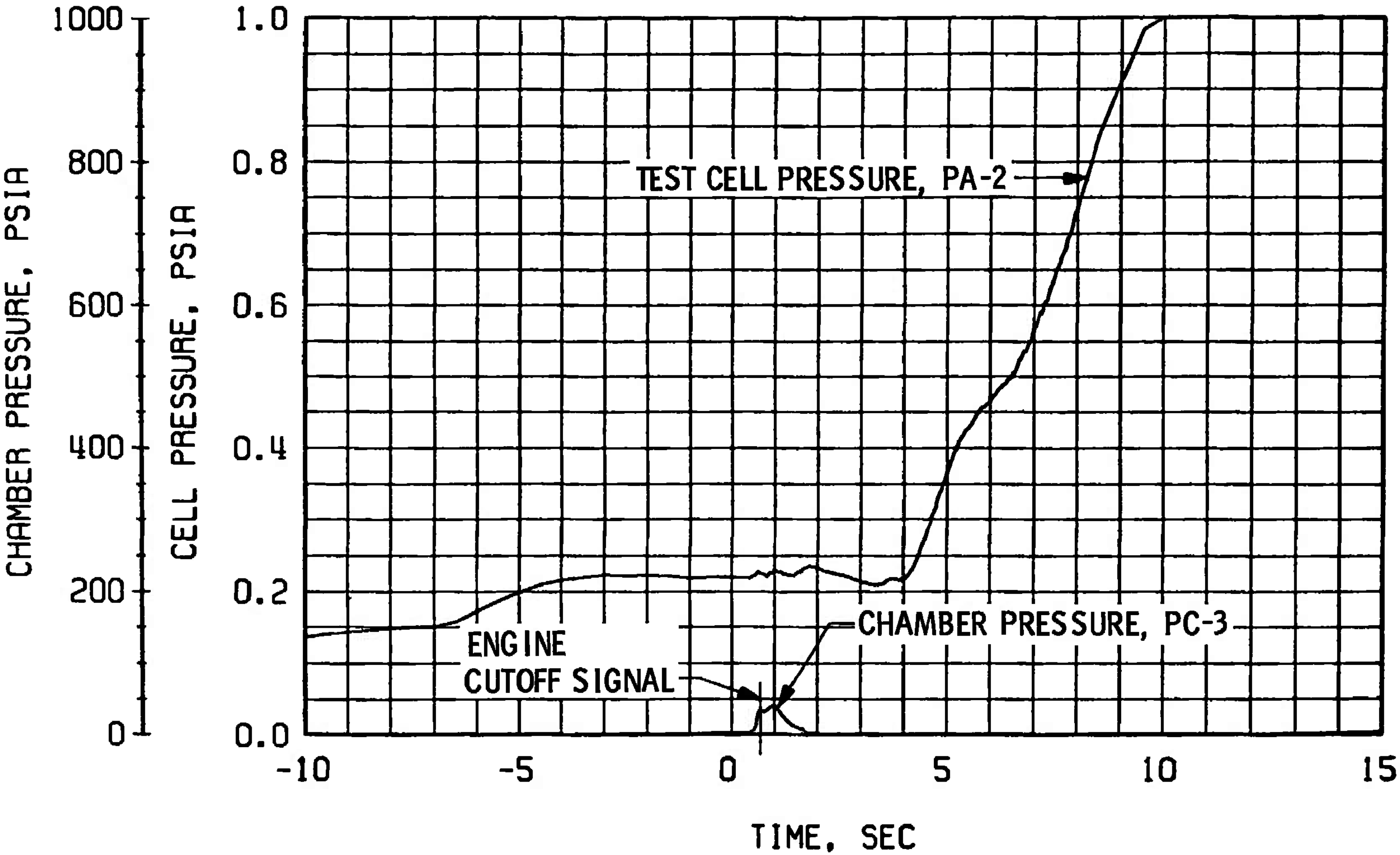
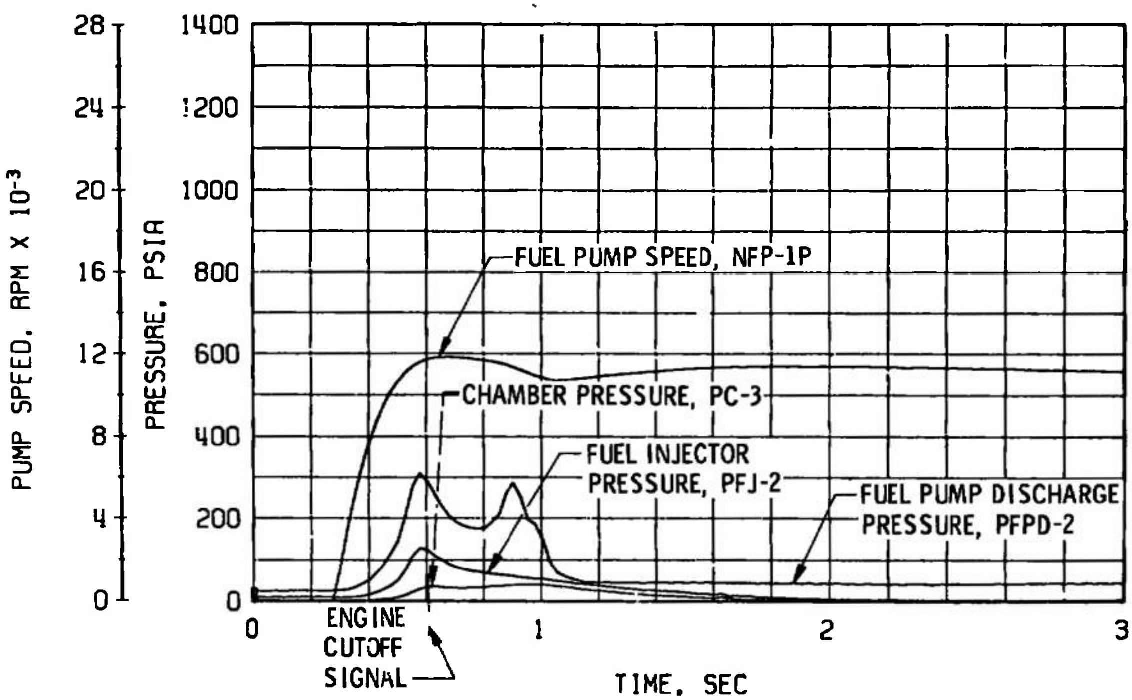
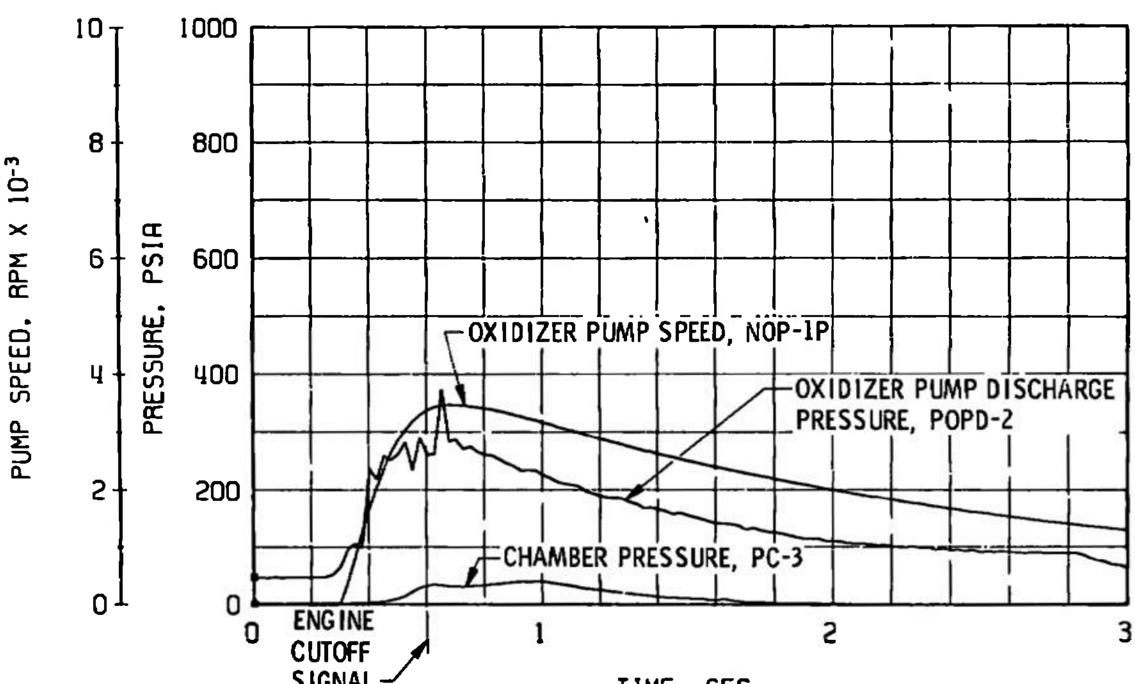


Fig. 71 Engine Ambient and Combustion Chamber Pressures, Firing 31E

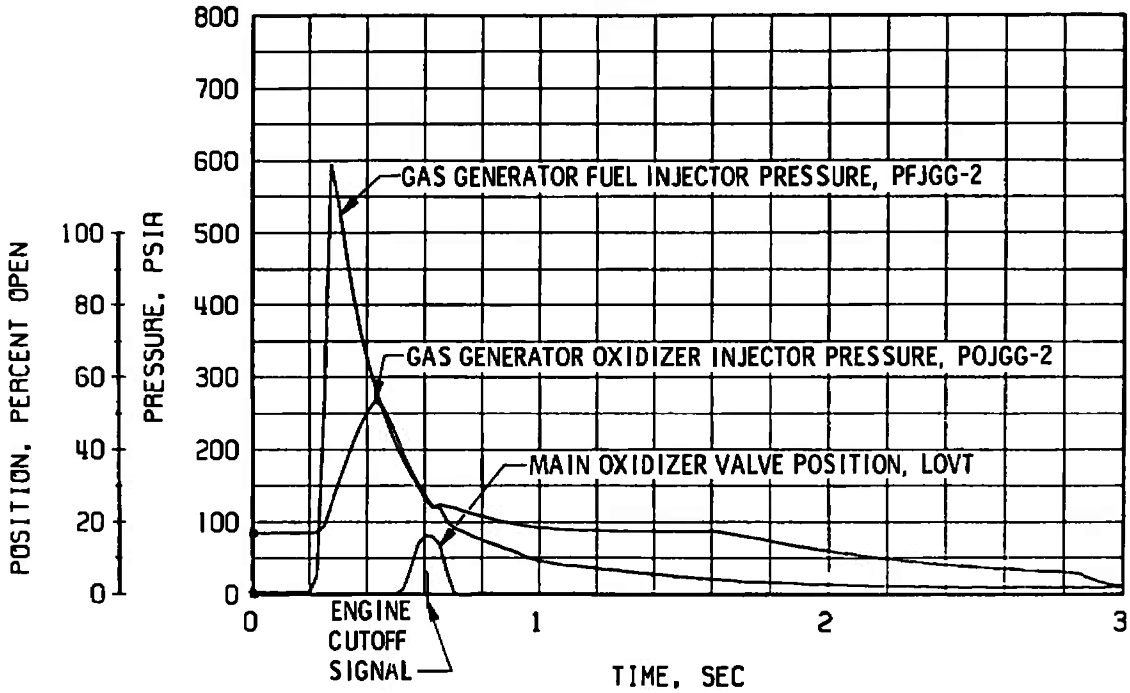


a. Thrust Chamber Fuel System, Start and Shutdown

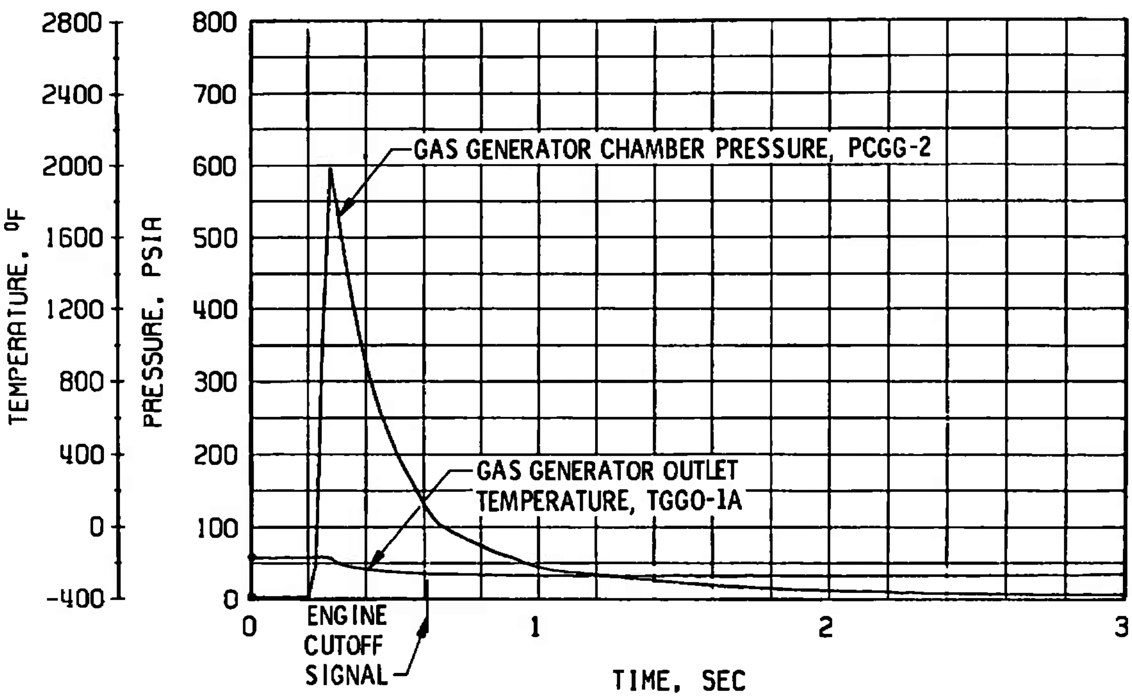


b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 72 Engine Transient Operation, Firing 31E



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 72 Concluded

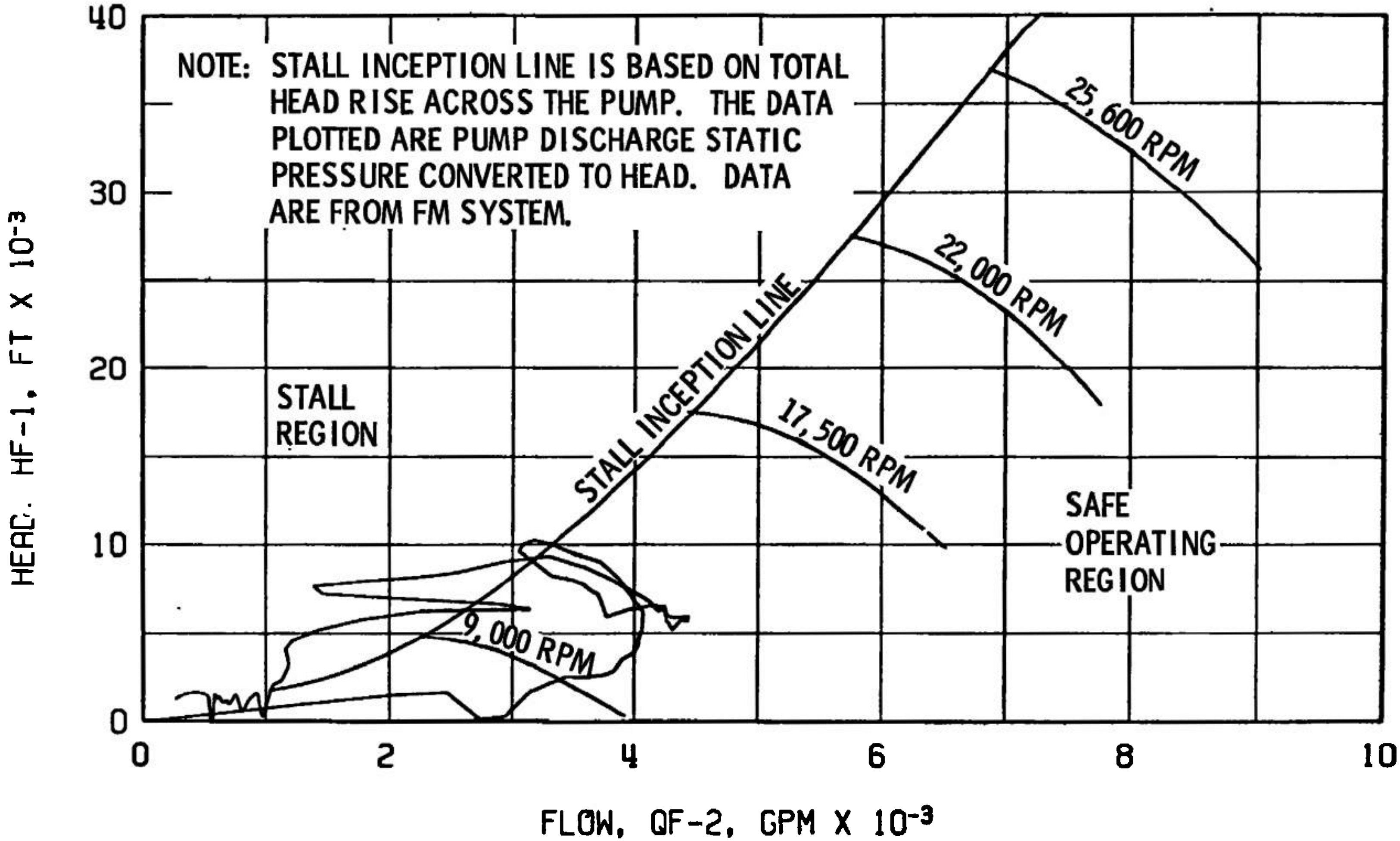
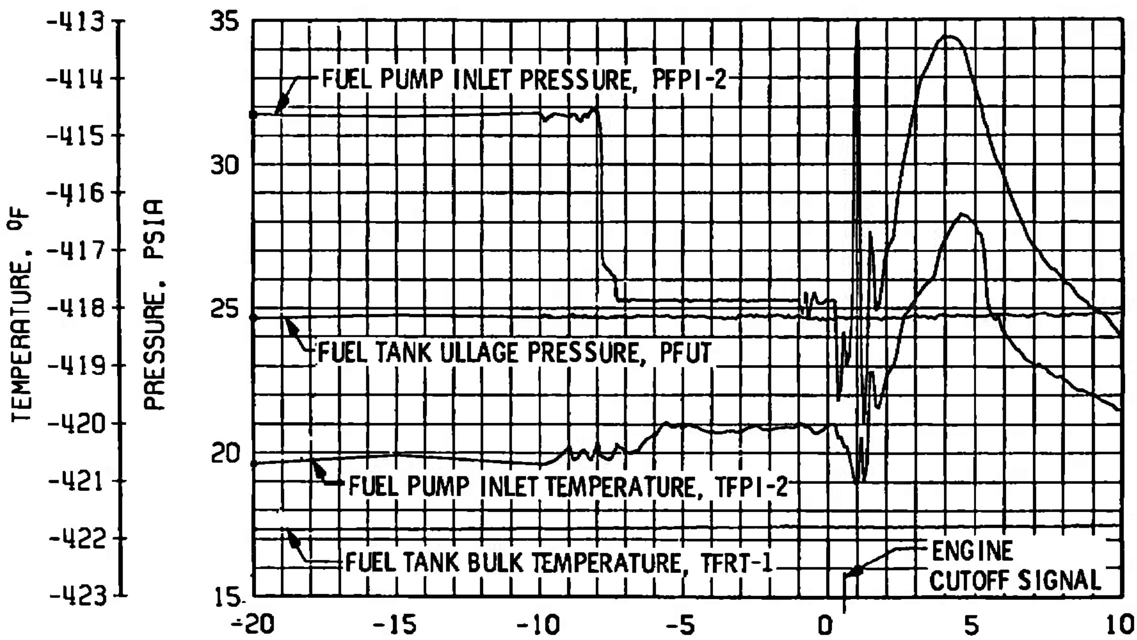
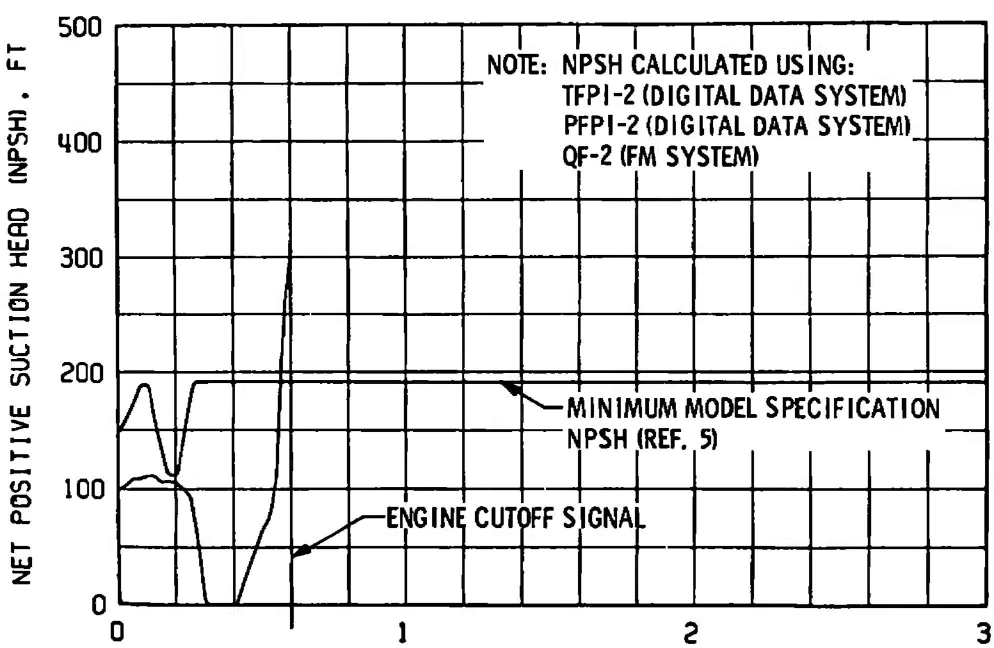


Fig. 73 Fuel Pump Start Transient Performance, Firing 31E

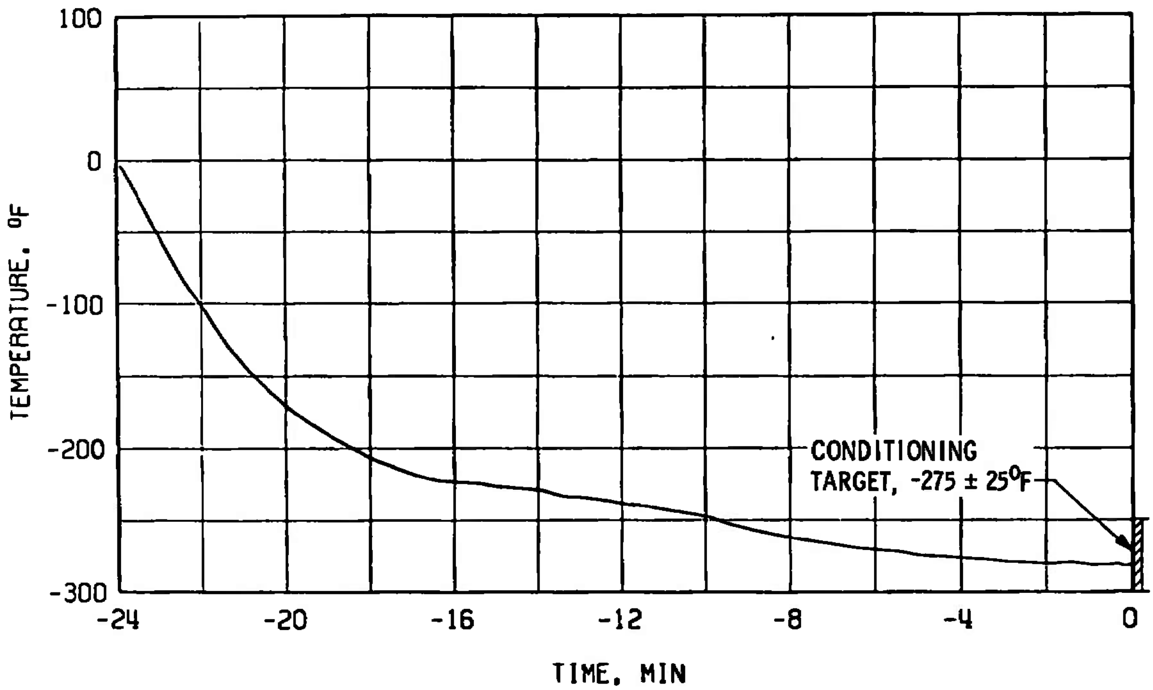


a. Duct Pressure and Temperature Transients

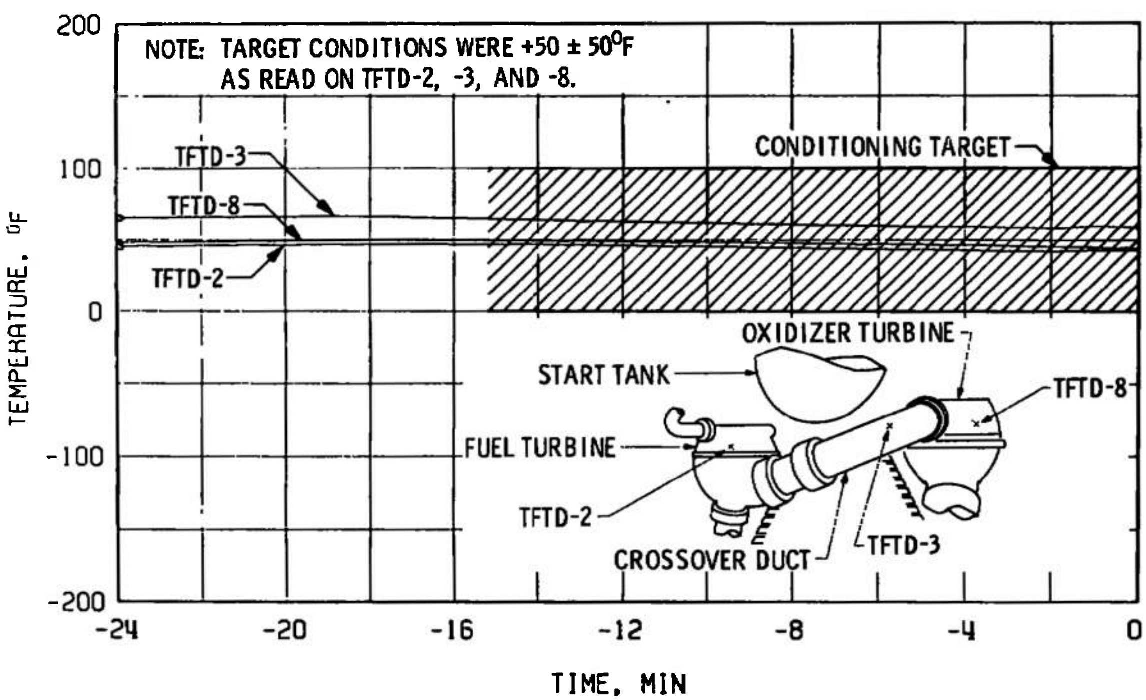


b. Fuel Pump NPSH during Start Transient, Firing 31E

Fig. 74 Fuel Low Pressure Duct Performance, Firing 31E

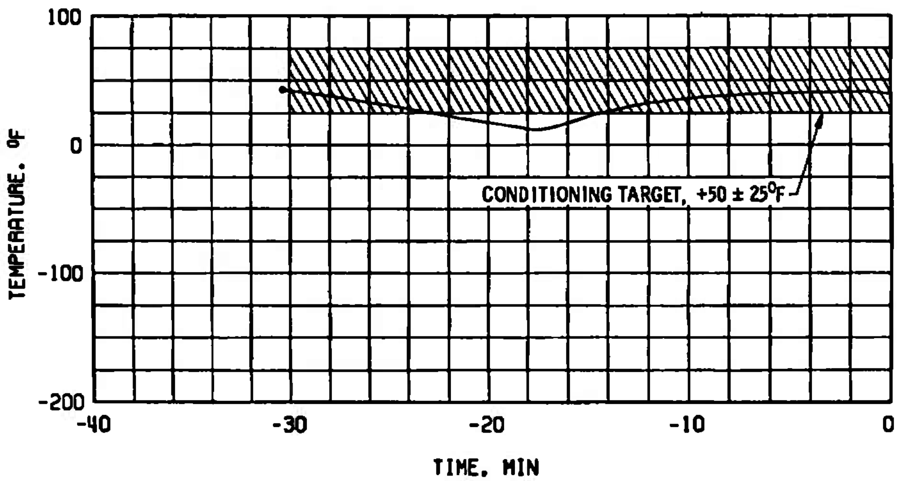


a. Thrust Chamber Throat, TTC-1P

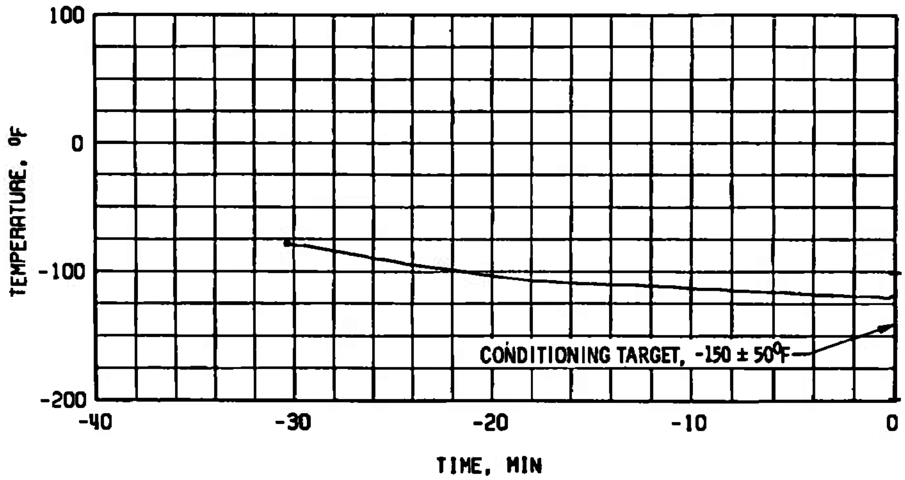


b. Crossover Duct, TFTD

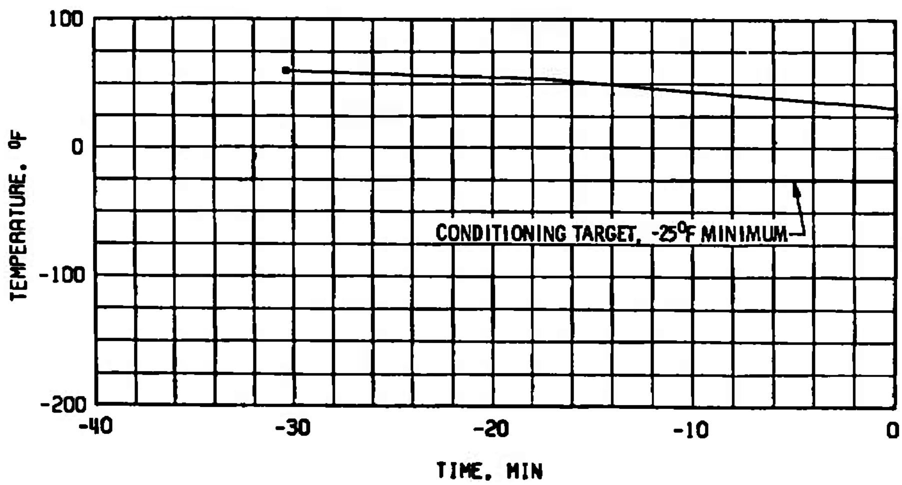
Fig. 75 Thermal Conditioning History of Engine Components, Firing 32A



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1



e. Gas Generator Valve Body, TGGVRS

Fig. 75 Concluded

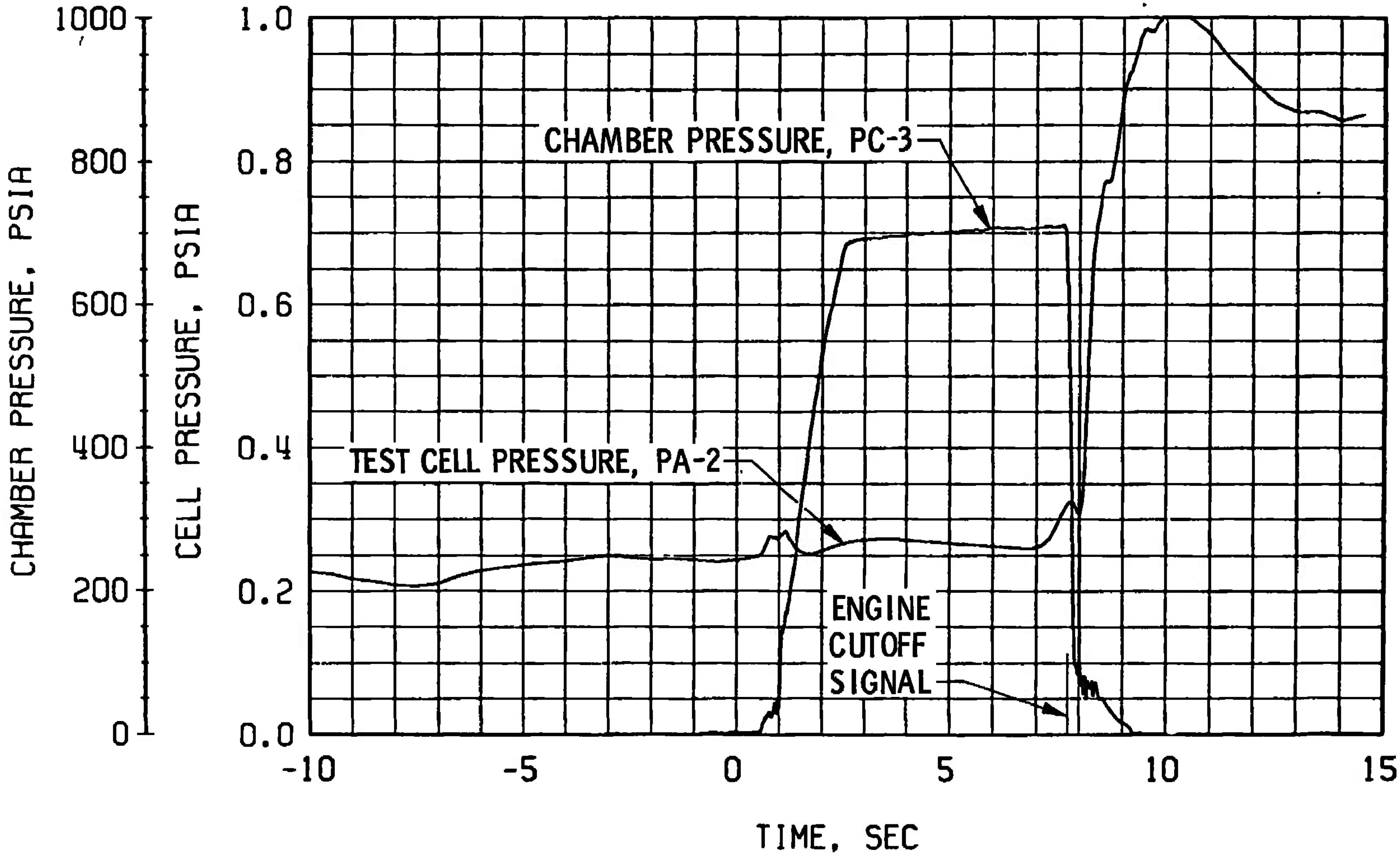
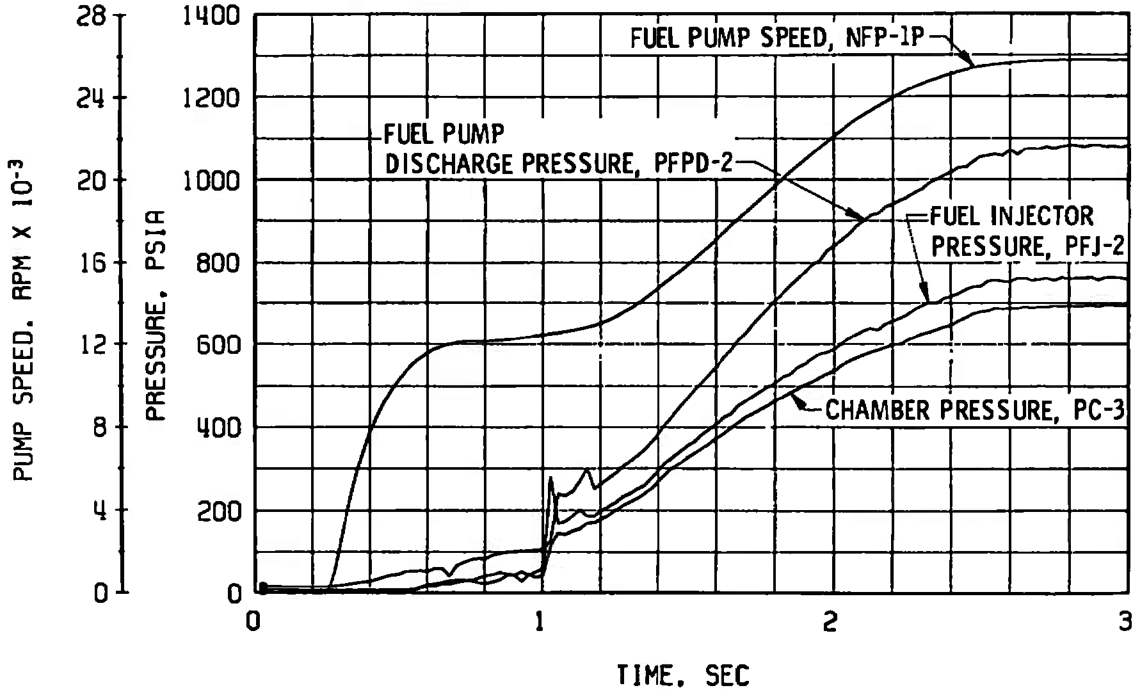
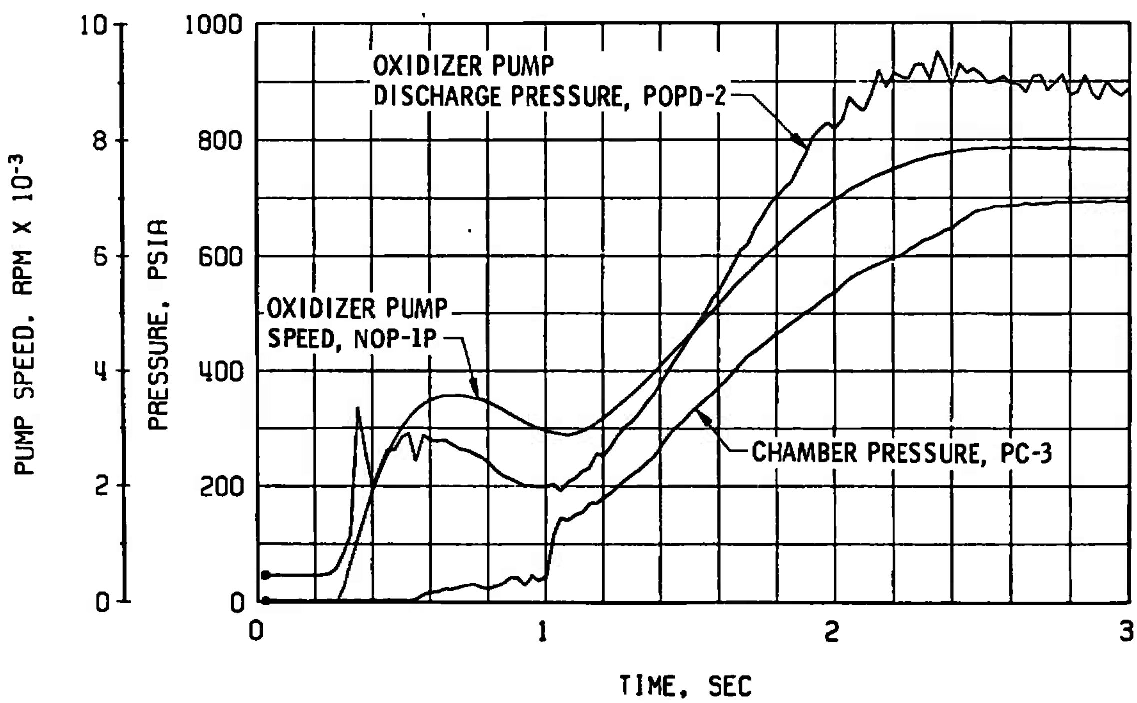


Fig. 76 Engine Ambient and Combustion Chamber Pressures, Firing 32A

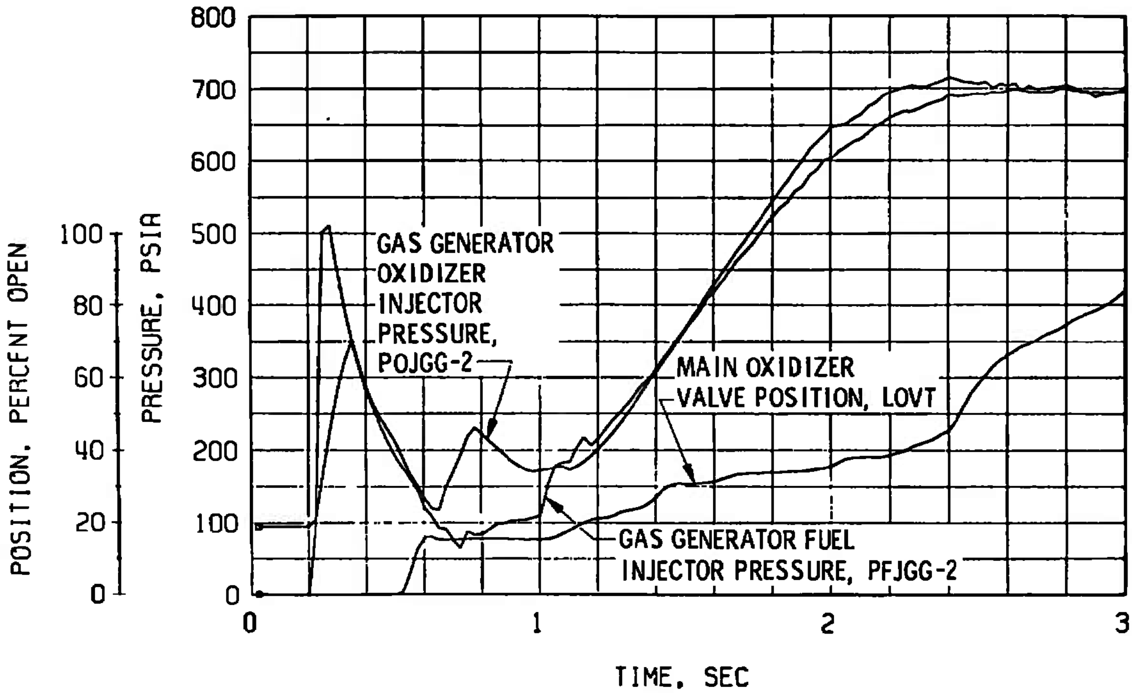


a. Thrust Chamber Fuel System, Start

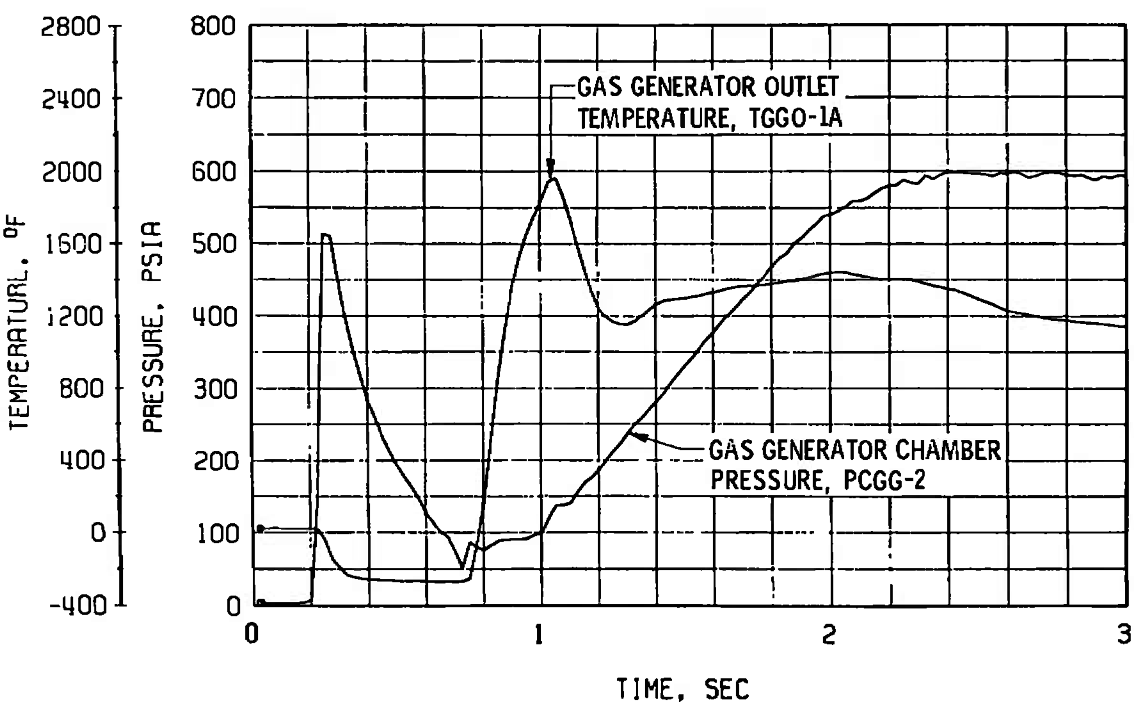


b. Thrust Chamber Oxidizer System, Start

Fig. 77 Engine Transient Operation, Firing 32A

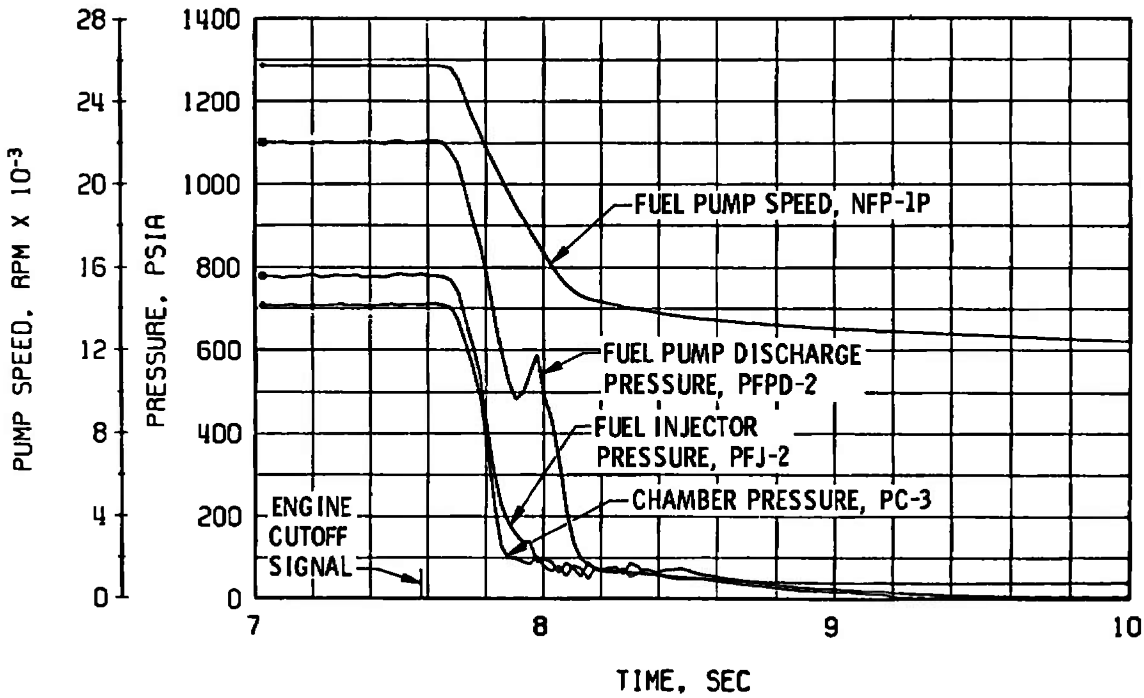


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

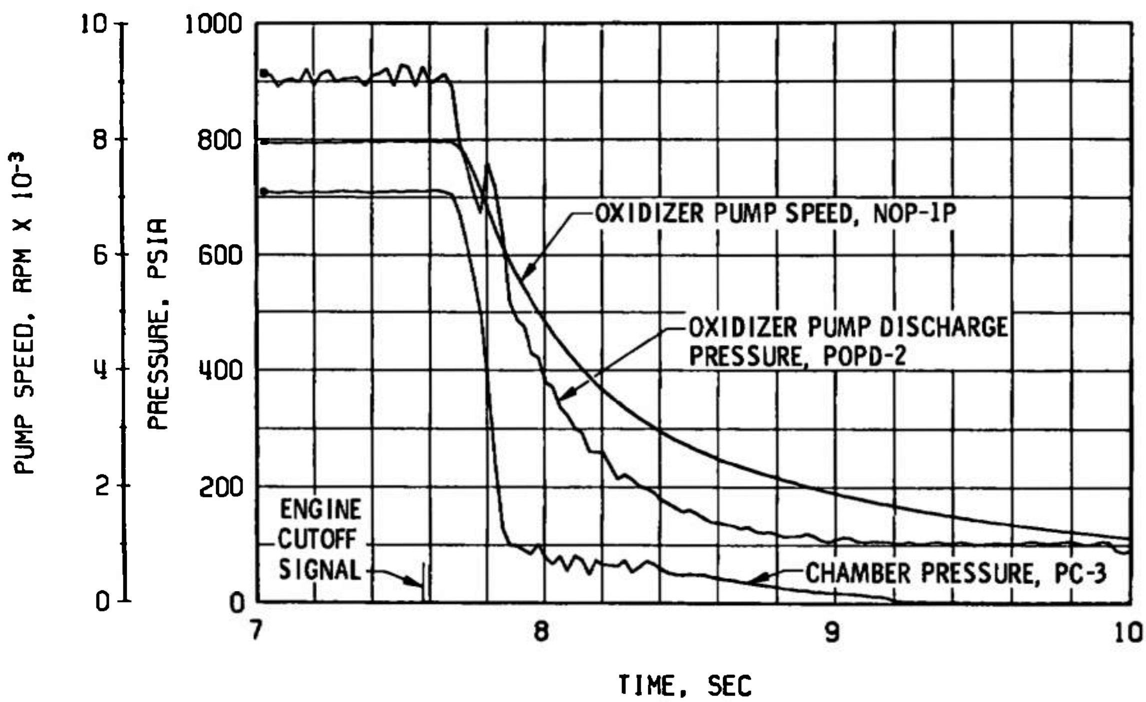


d. Gas Generator Chamber Pressure and Temperature, Start

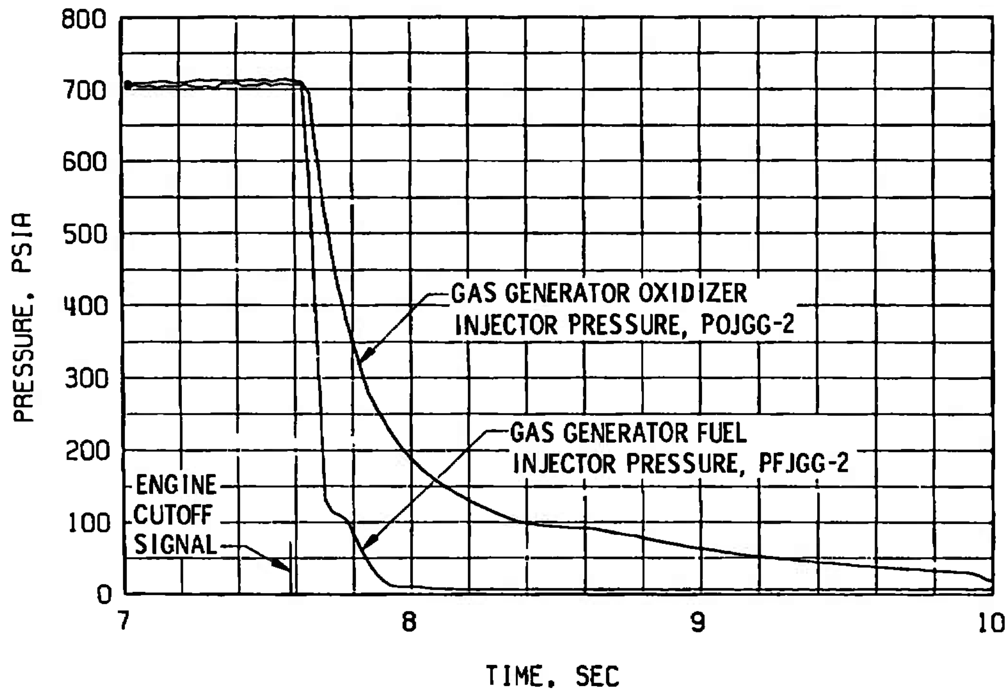
Fig. 77 Continued



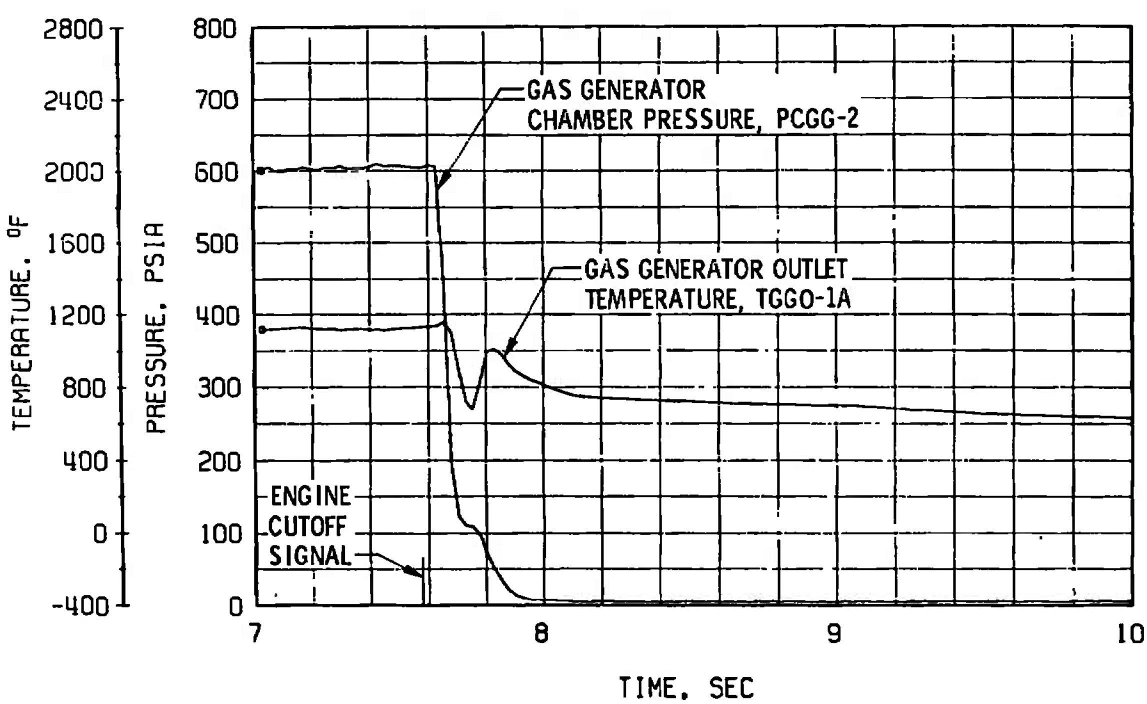
e. Thrust Chamber Fuel System, Shutdown



f. Thrust Chamber Oxidizer System, Shutdown
Fig. 77 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 77 Concluded

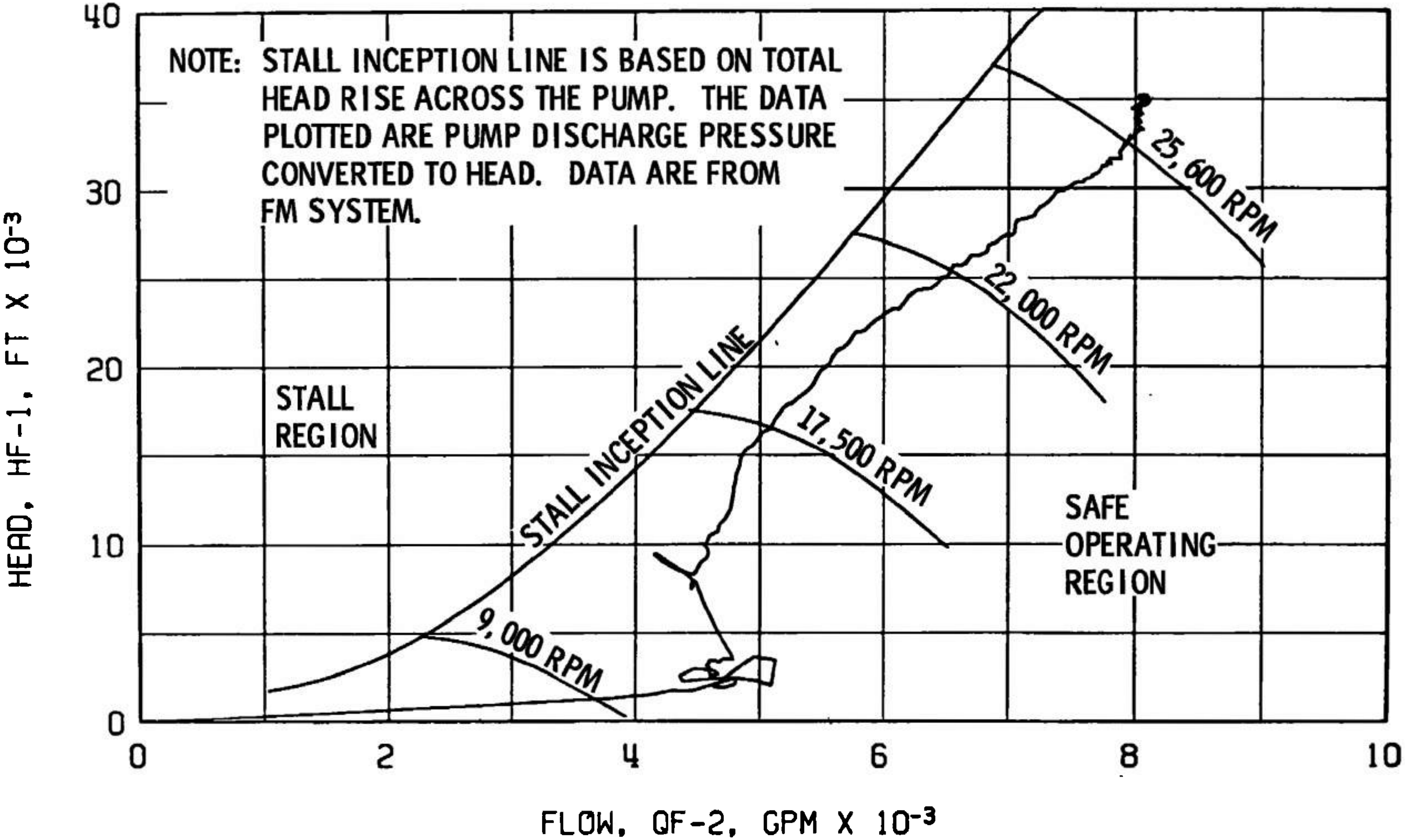
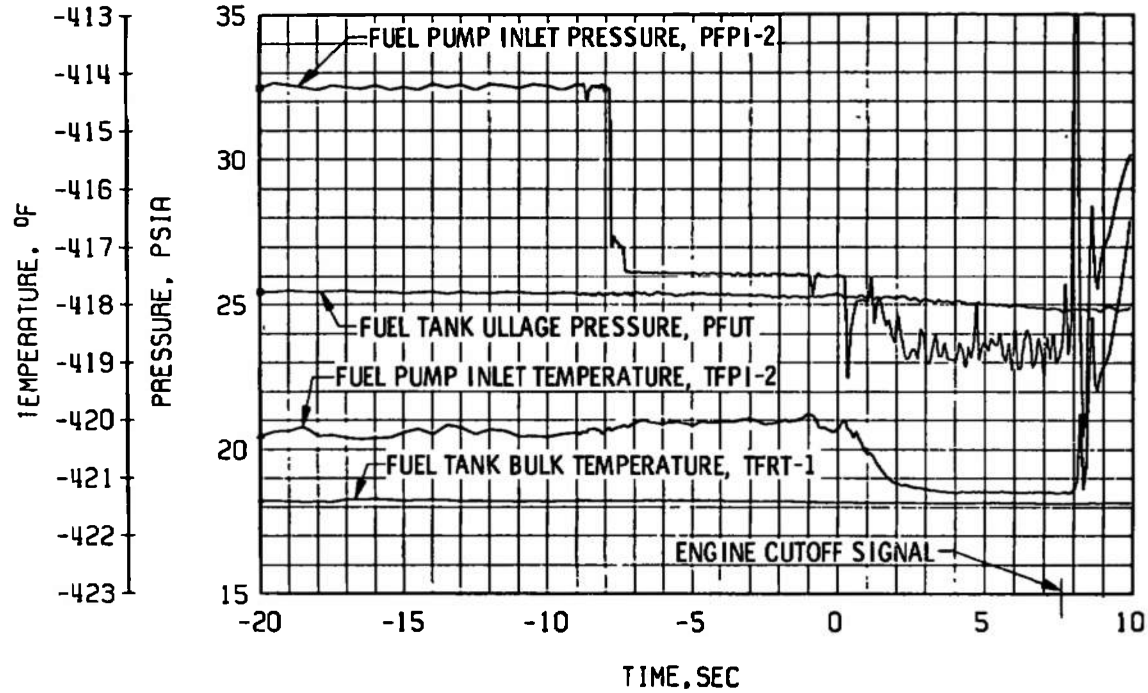
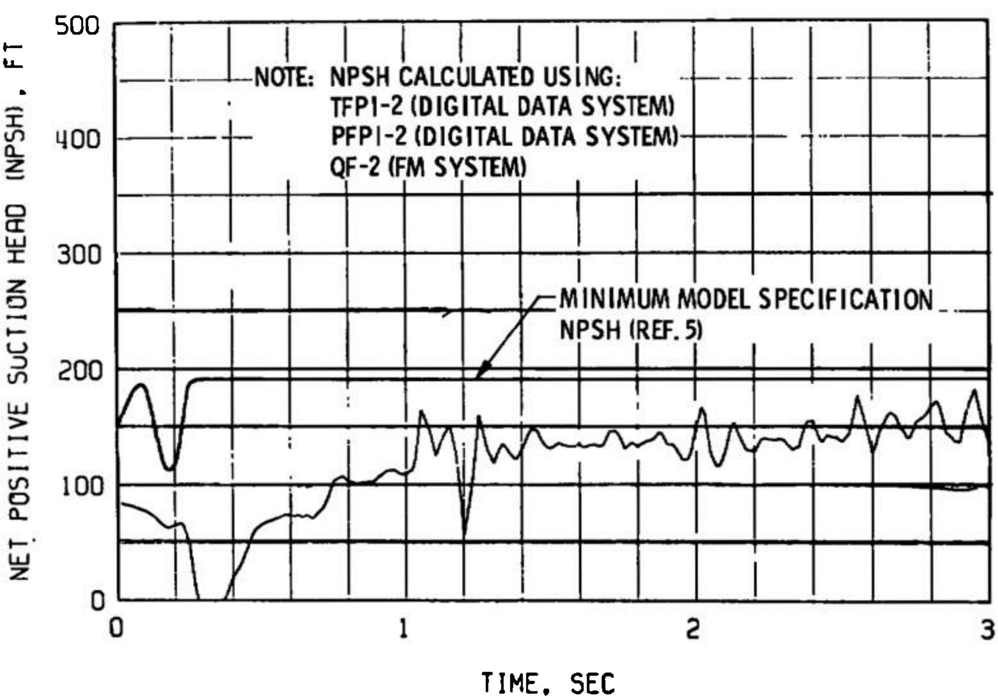


Fig. 78 Fuel Pump Start Transient Performance, Firing 32A

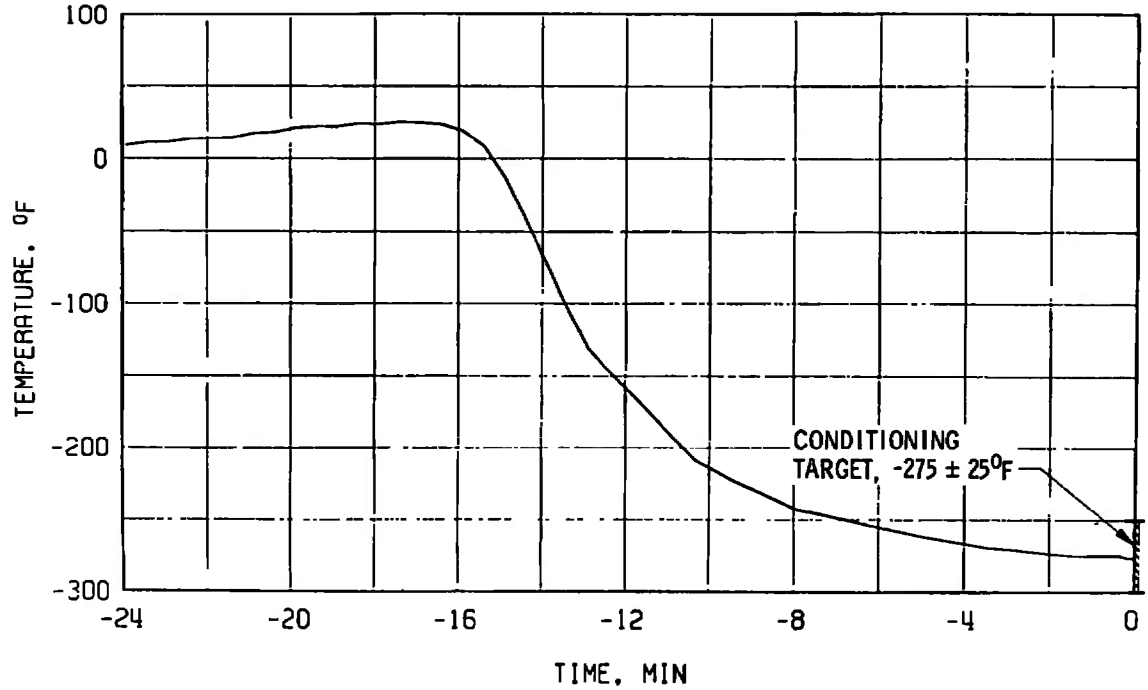


a. Duct Pressure and Temperature Transients

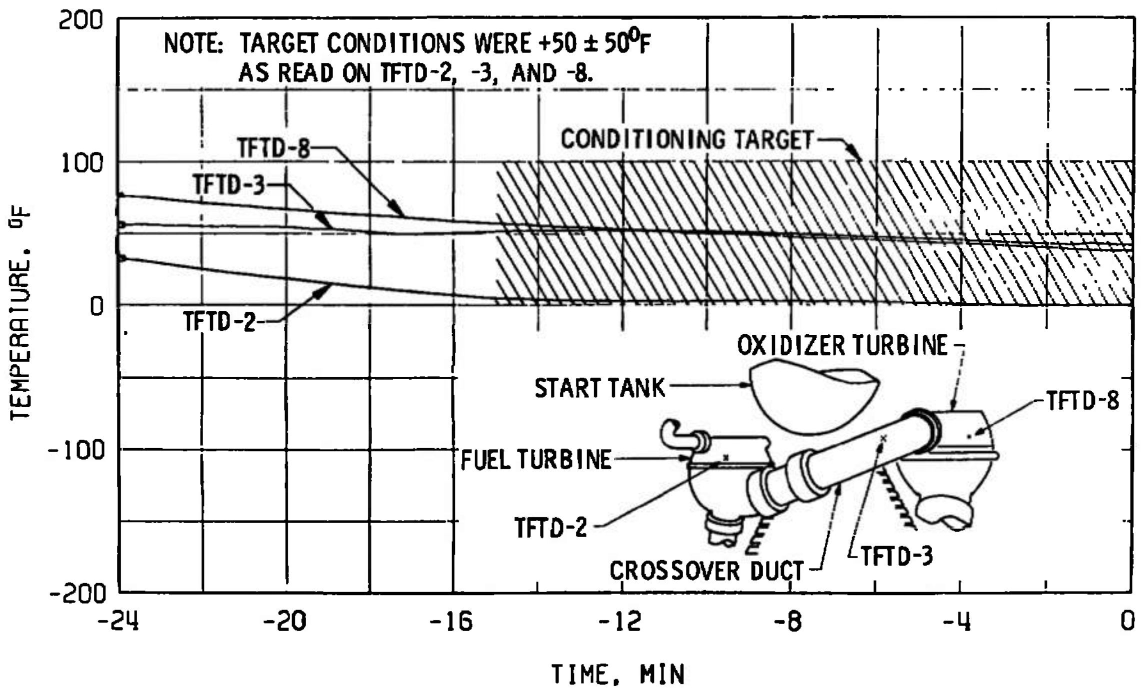


b. Fuel Pump NPSH during Start Transient, Firing 32A

Fig. 79 Fuel Low Pressure Duct Performance, Firing 32A

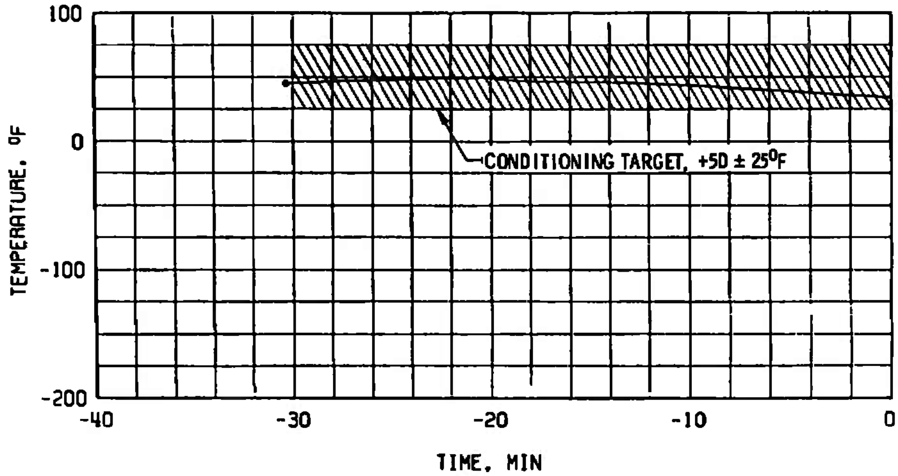


a. Thrust Chamber Throat, TTC-1P

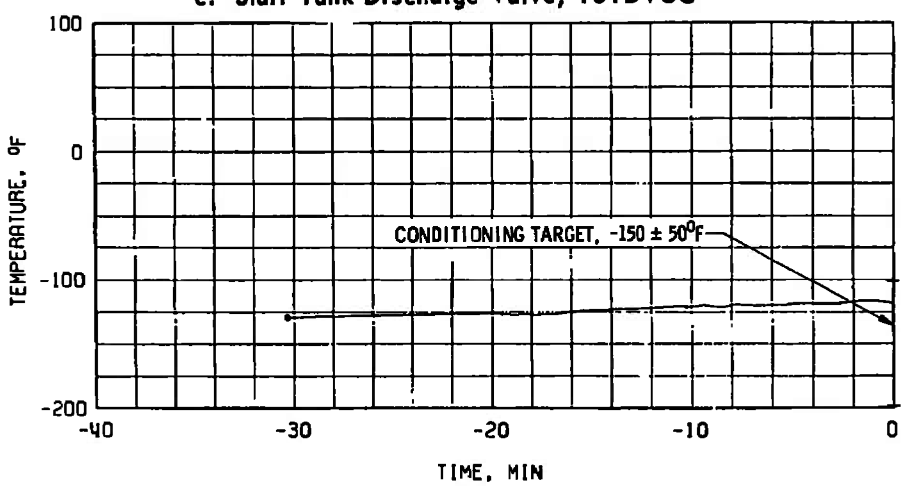


b. Crossover Duct, TFTD

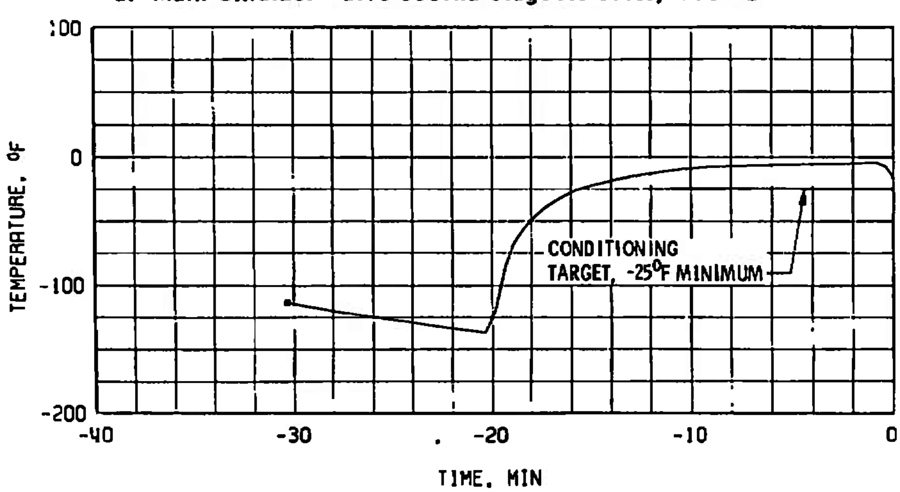
Fig. 80 Thermal Conditioning History of Engine Components, Firing 32B



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1



e. Gas Generator Valve Body, TGGVRS

Fig. 80 Concluded

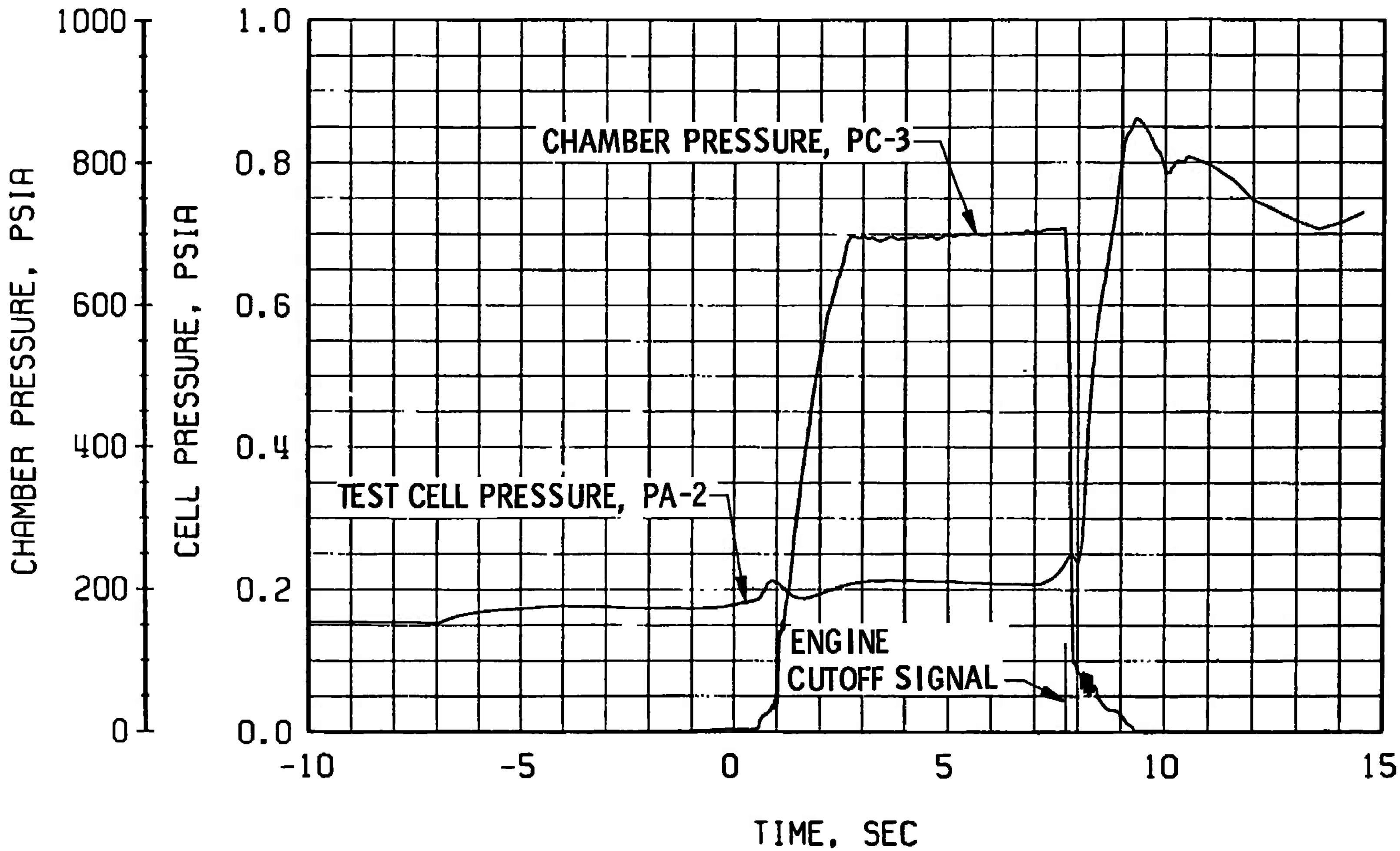
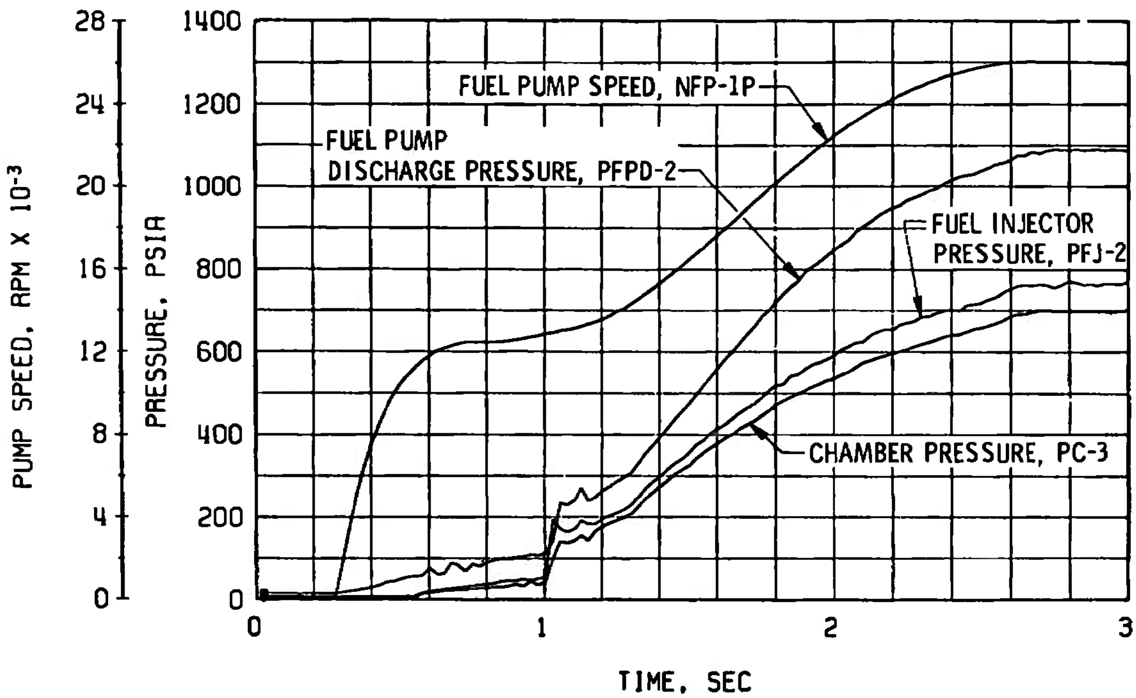
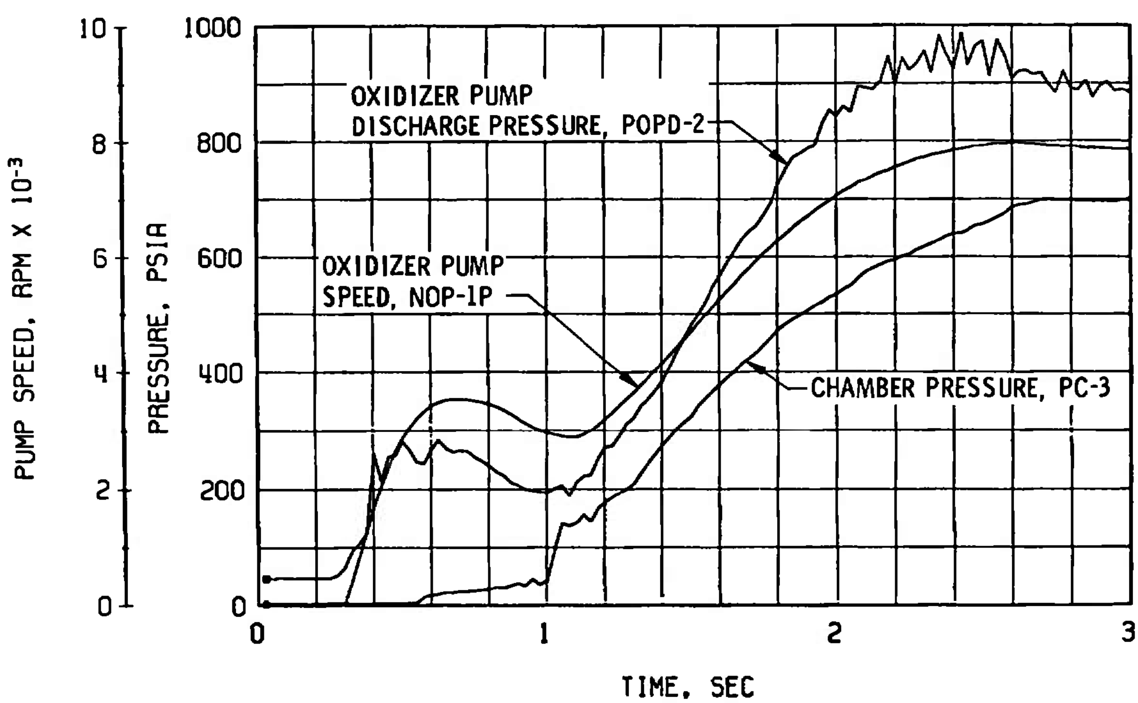


Fig. 81 Engine Ambient and Combustion Chamber Pressures, Firing 32B

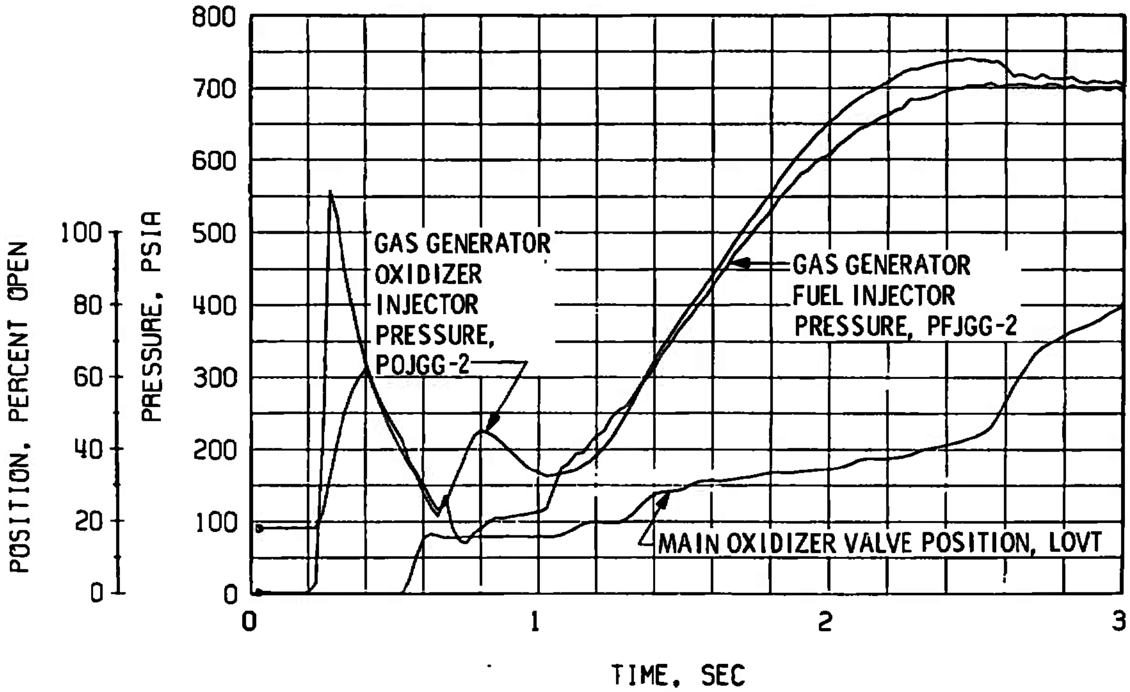


a. Thrust Chamber Fuel System, Start

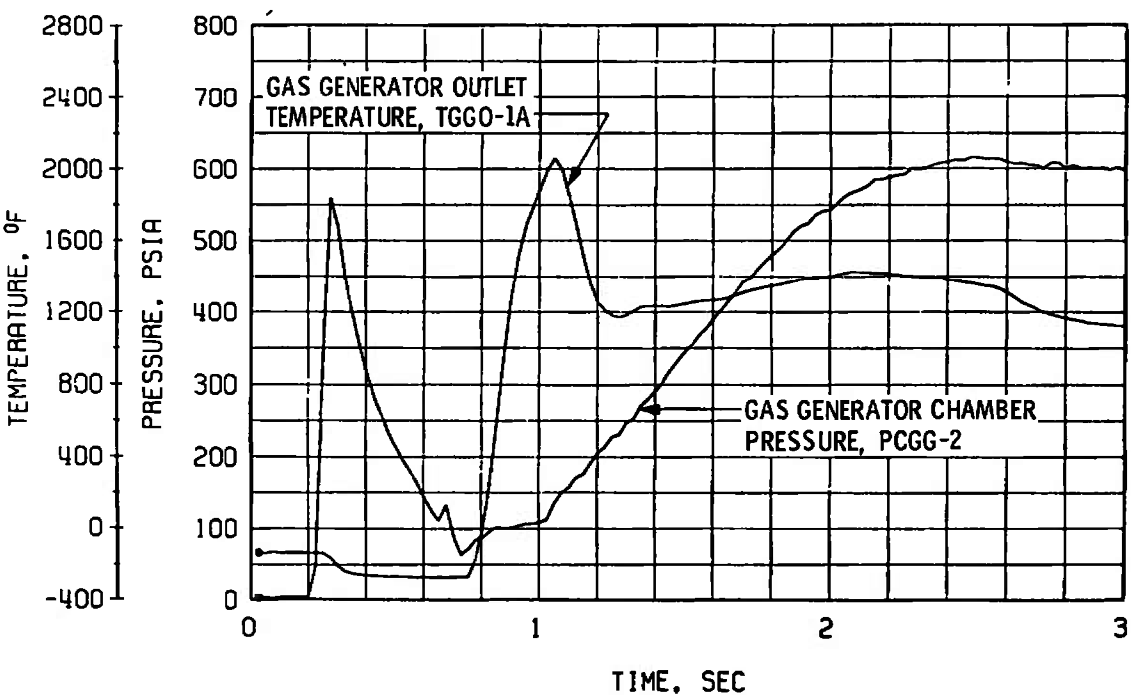


b. Thrust Chamber Oxidizer System, Start

Fig. 82 Engine Transient Operation, Firing 32B

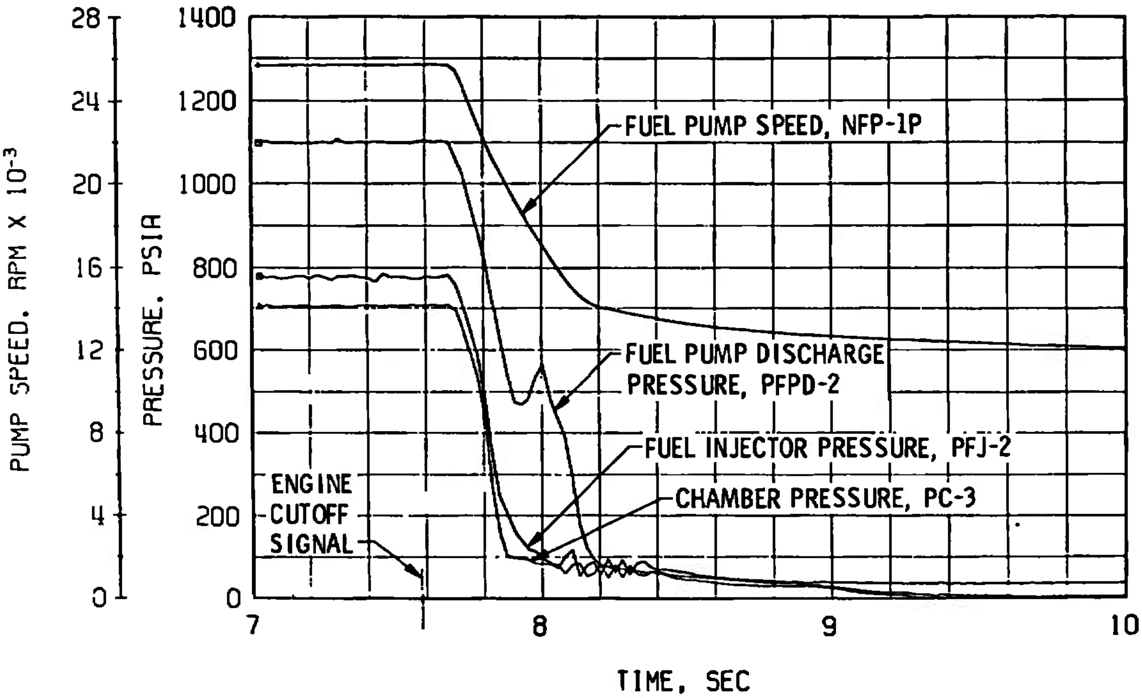


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

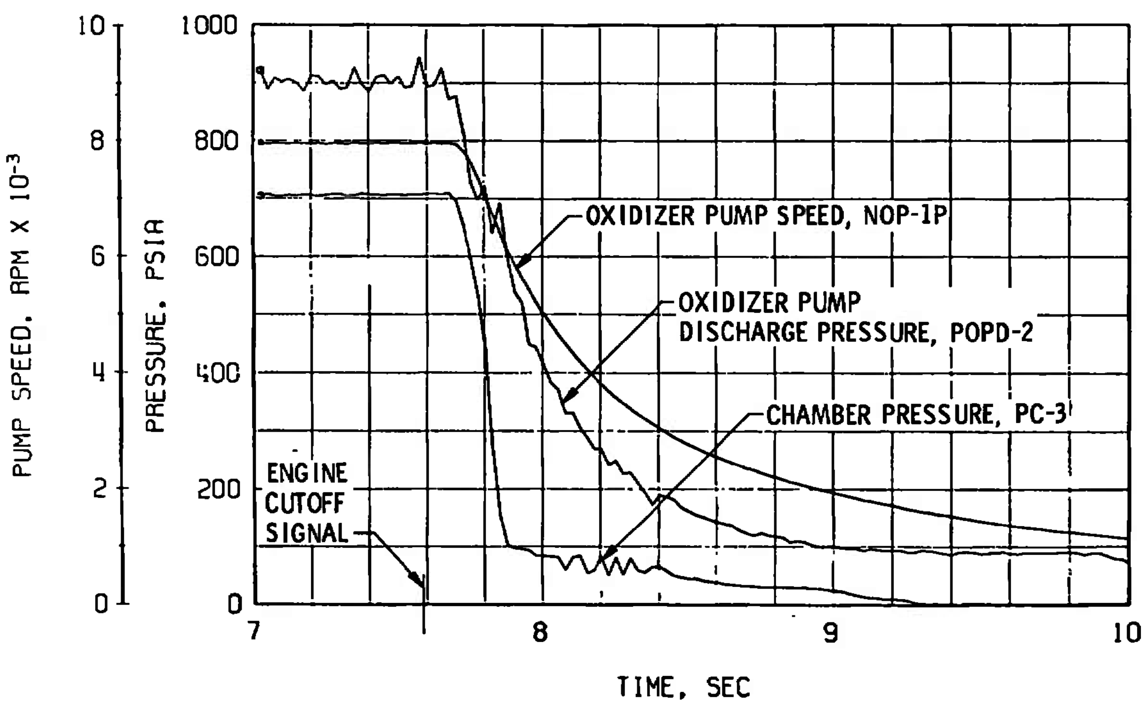


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 82 Continued

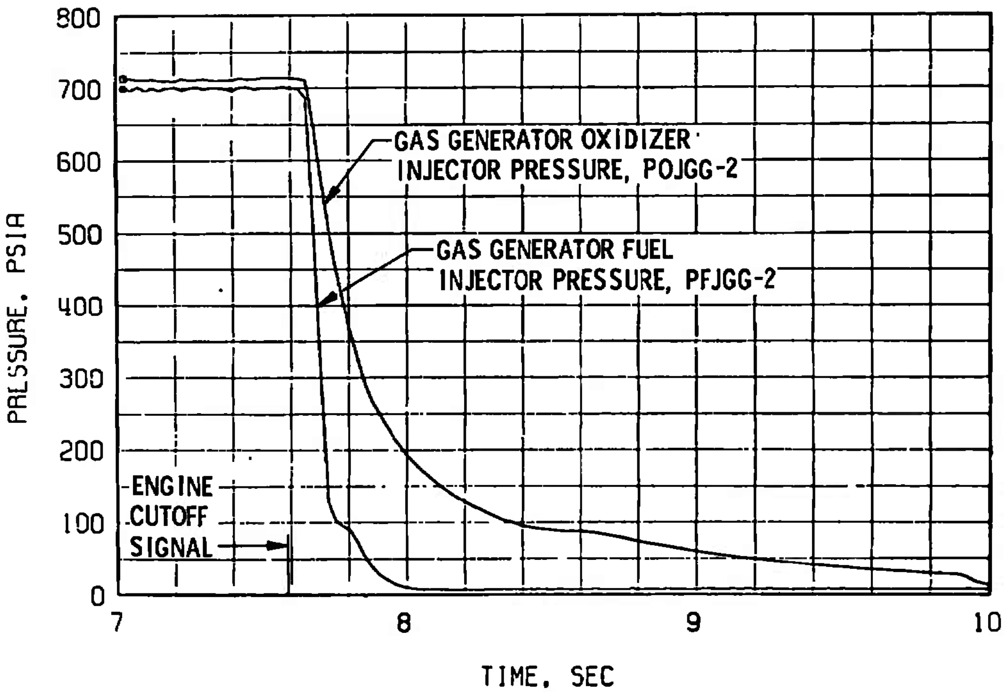


e. Thrust Chamber Fuel System, Shutdown

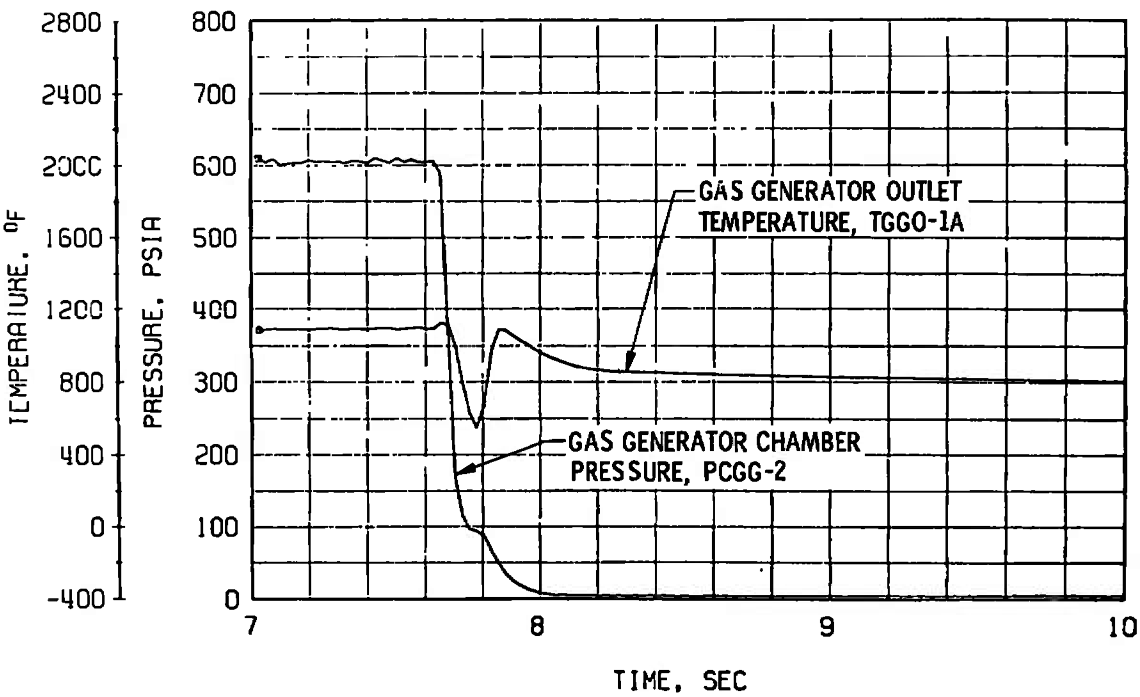


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 82 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 82 Concluded

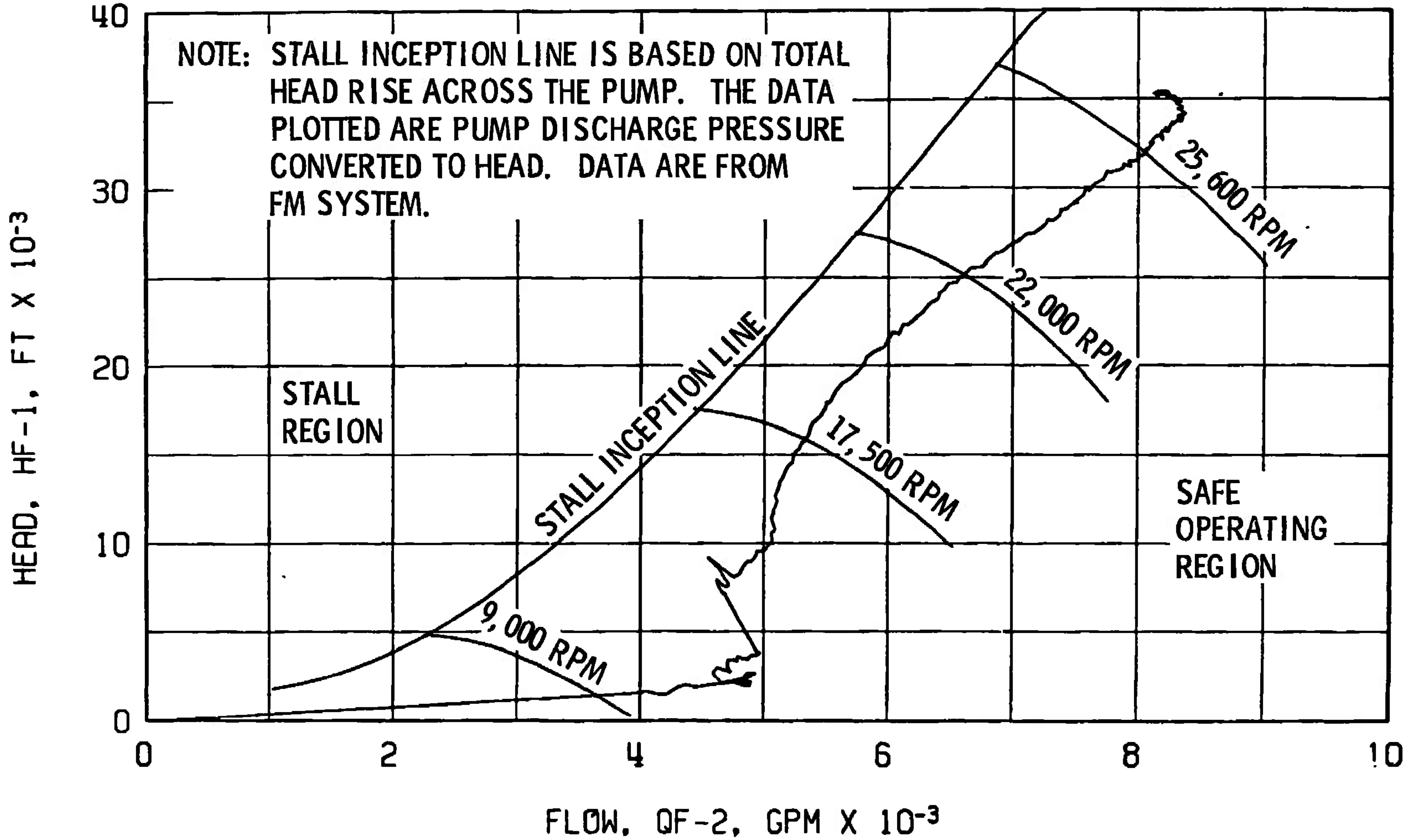
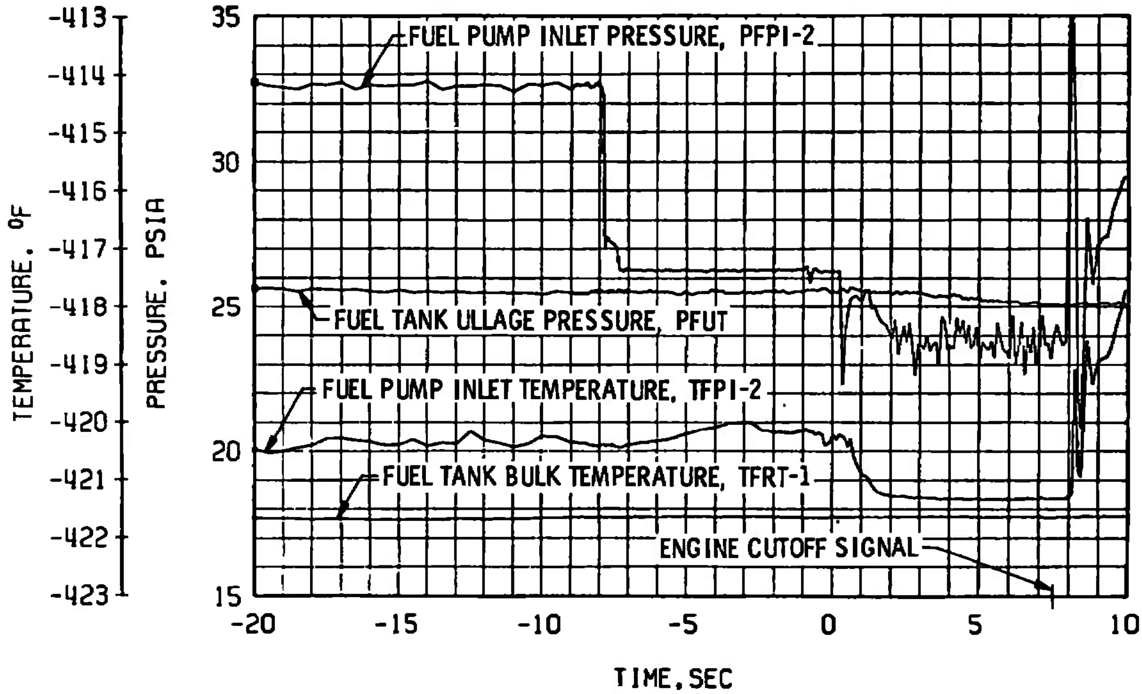
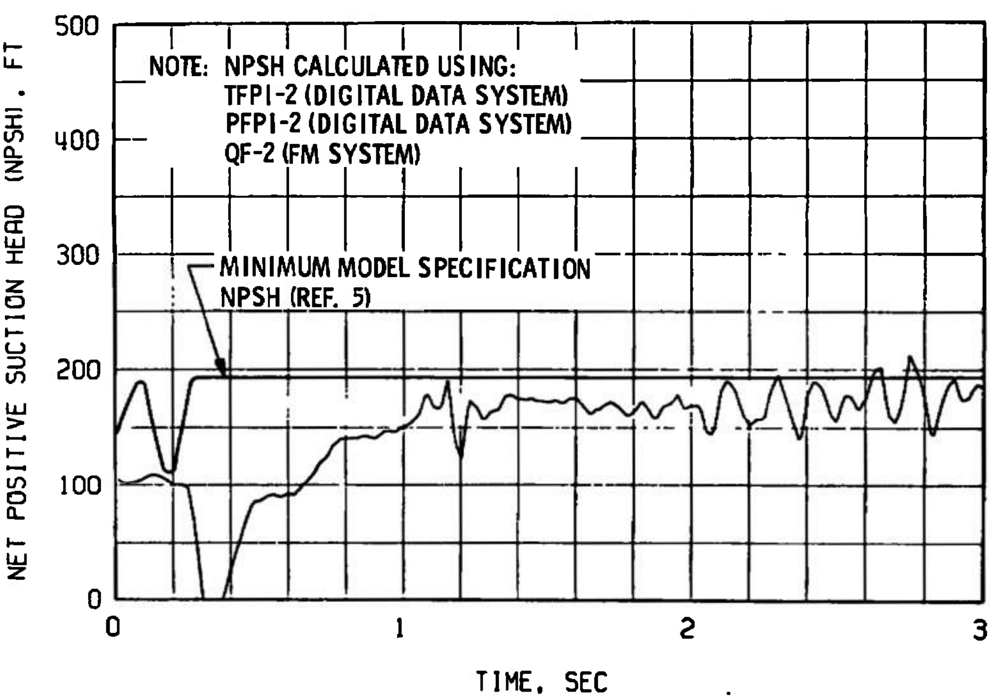


Fig. 83 Fuel Pump Start Transient Performance, Firing 32B

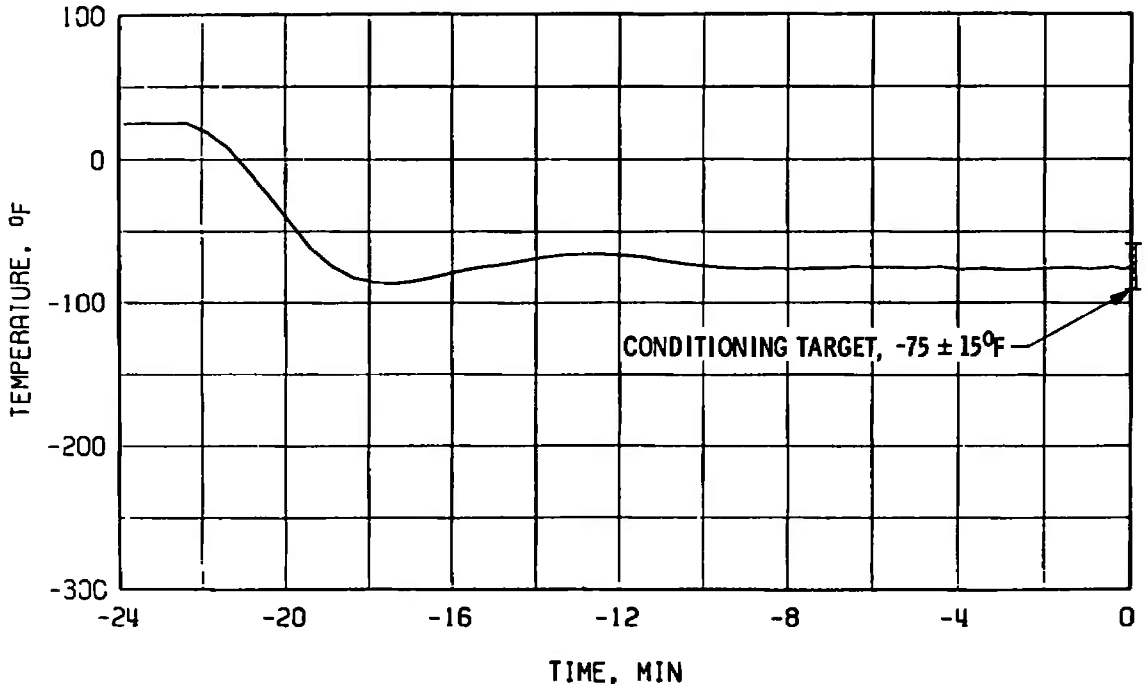


a. Duct Pressure and Temperature Transients

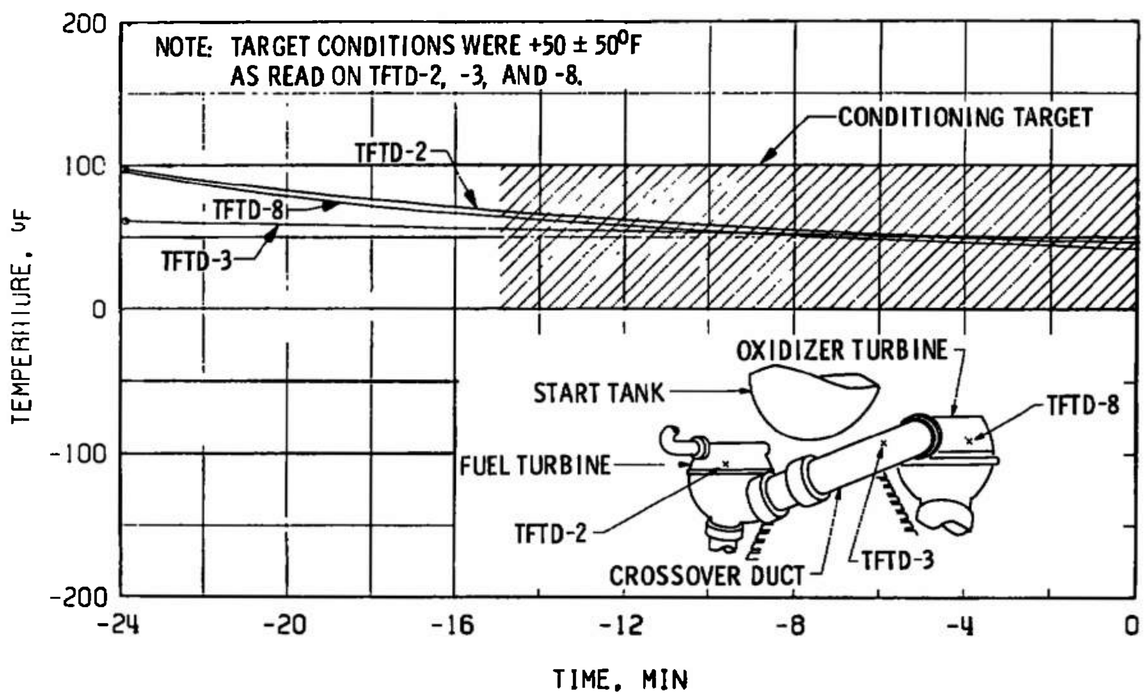


b. Fuel Pump NPSH during Start Transient, Firing 32B

Fig. 84 Fuel Low Pressure Duct Performance, Firing 32B

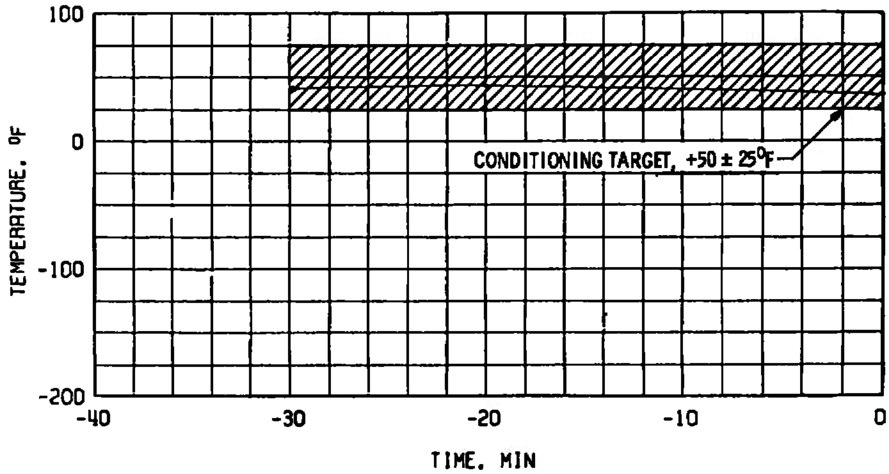


a. Thrust Chamber Throat, TTC-1P

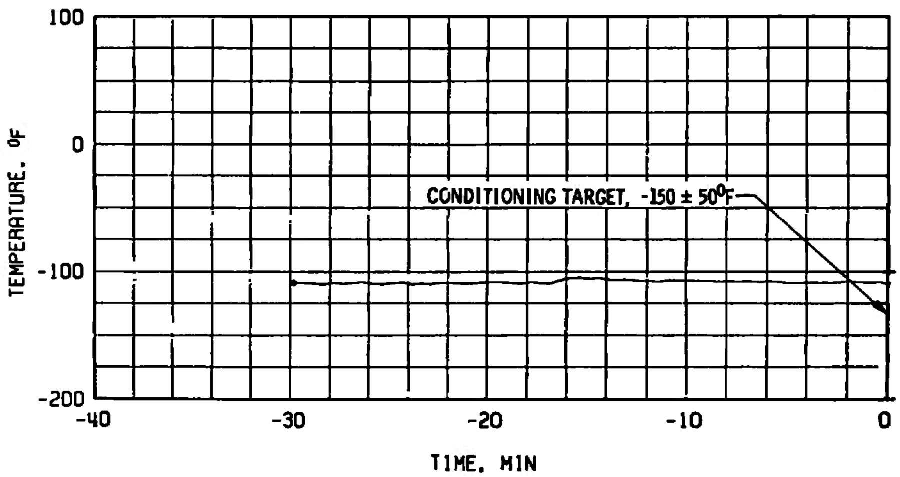


b. Crossover Duct, TFTD

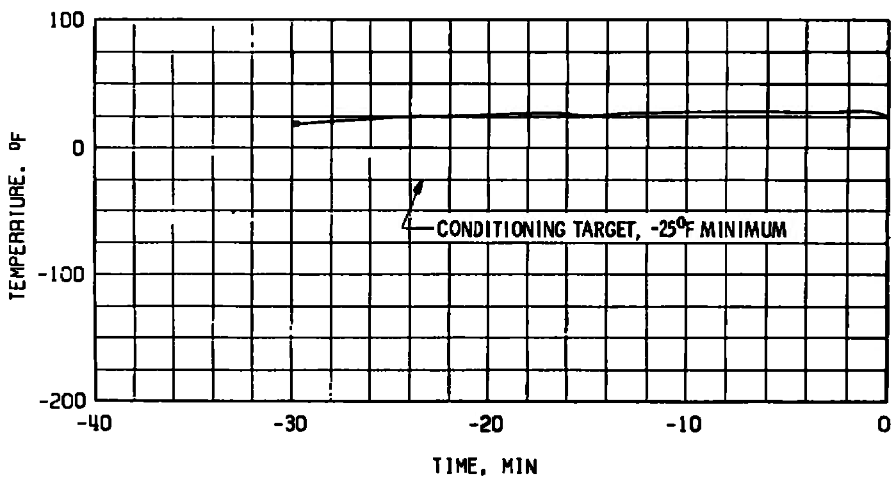
Fig. 85 Thermal Conditioning History of Engine Components, Firing 32C



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1



e. Gas Generator Body Temperature, TGGVRS

Fig. 85 Concluded

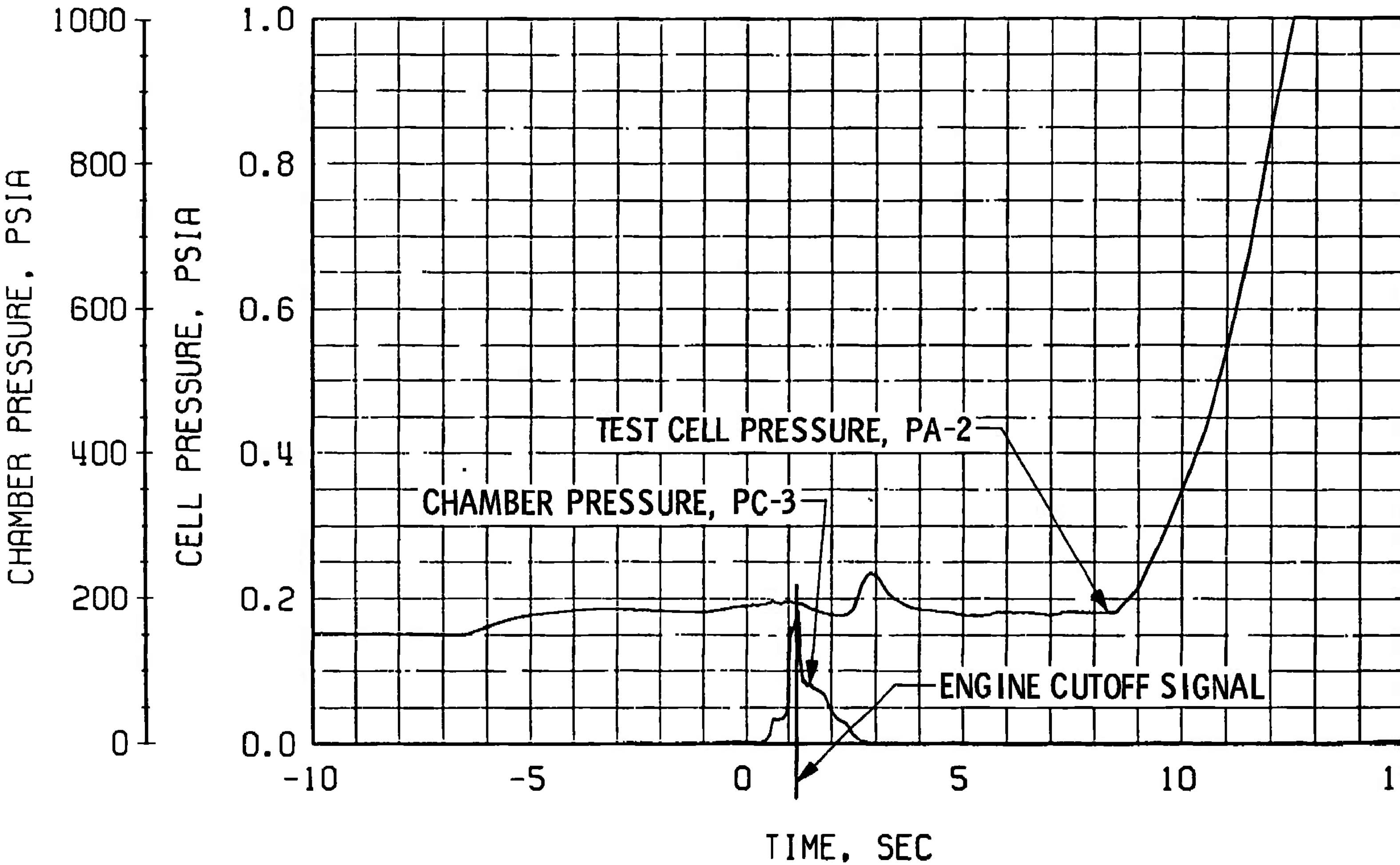
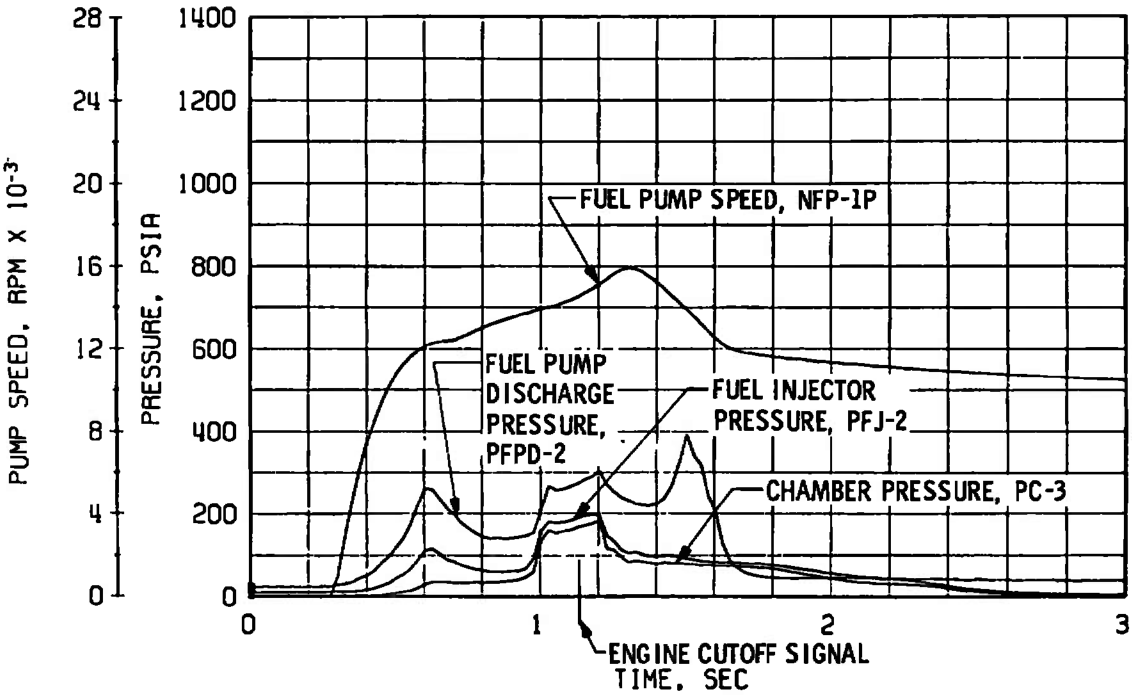
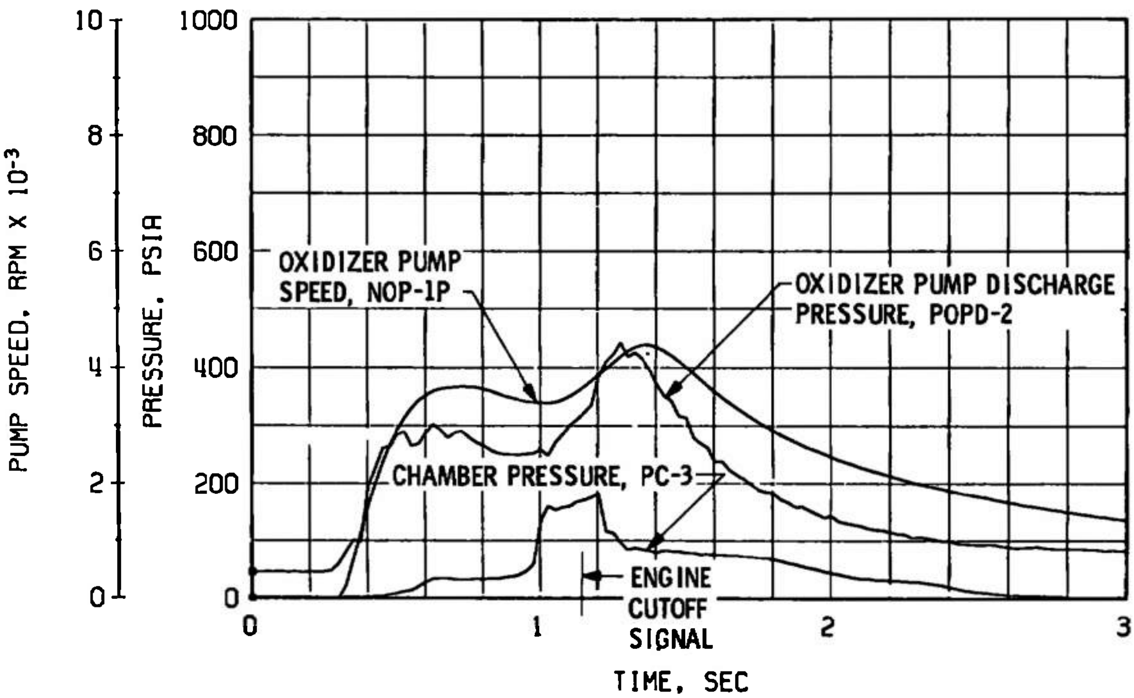


Fig. 86 Engine Ambient and Combustion Chamber Pressures, Firing 32C

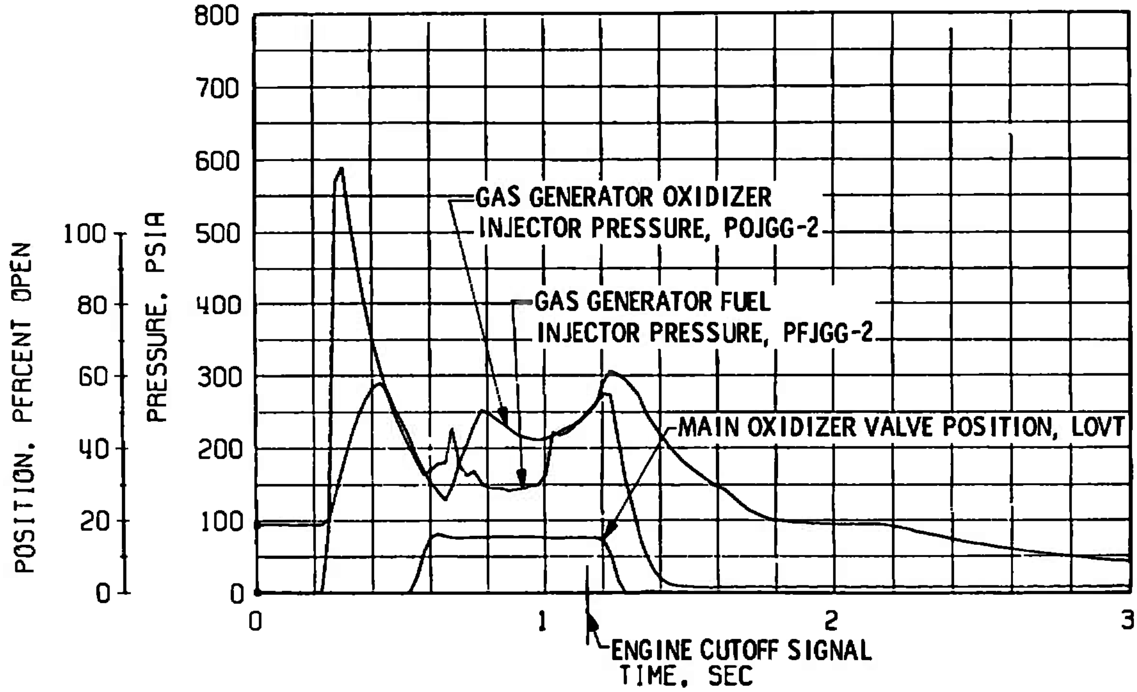


a. Thrust Chamber Fuel System, Start and Shutdown

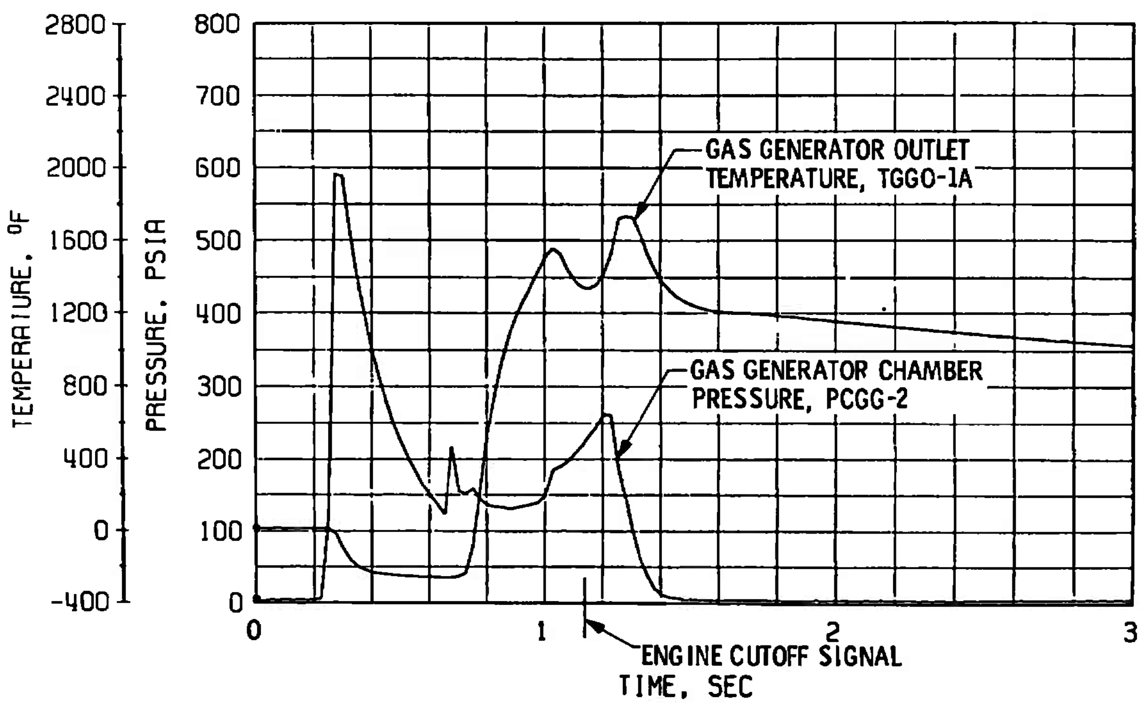


b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 87 Engine Transient Operation, Firing 32C



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 87 Concluded

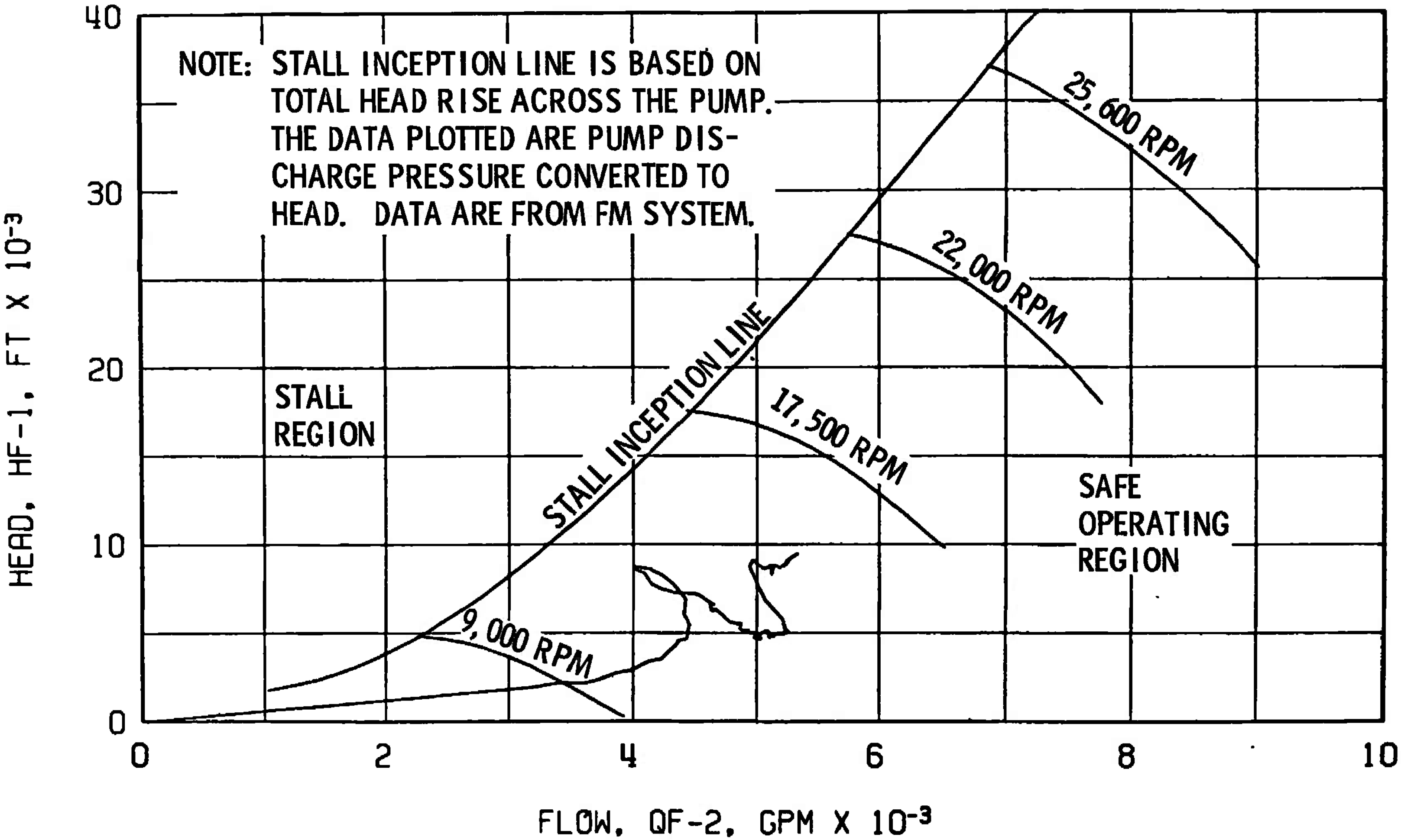
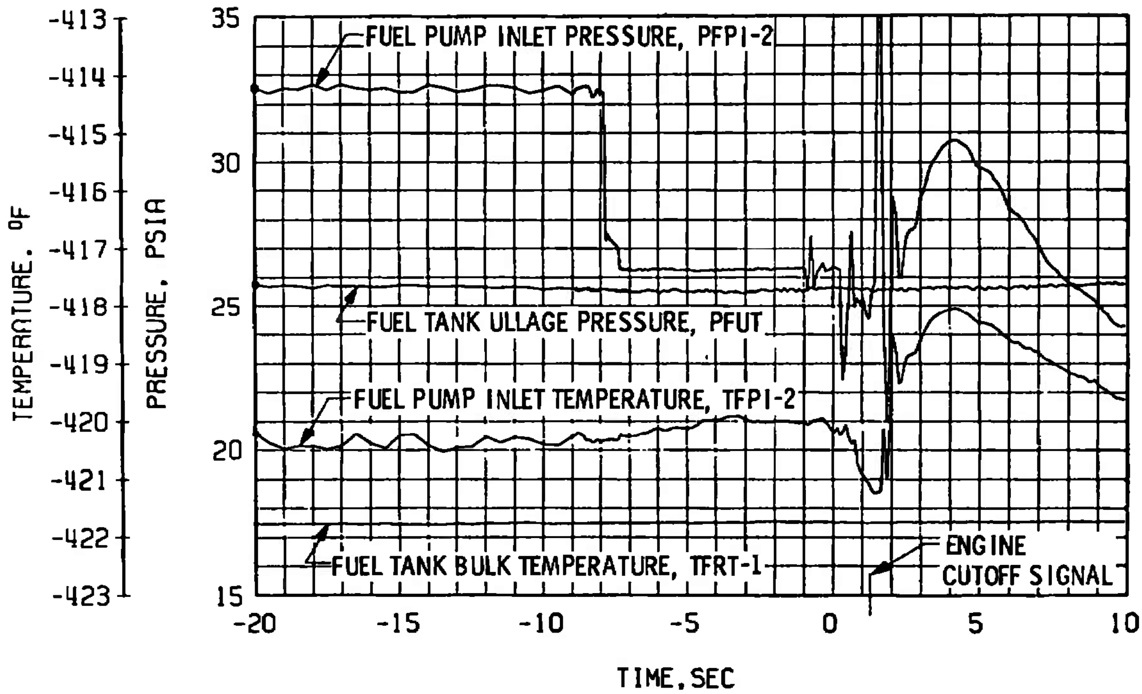
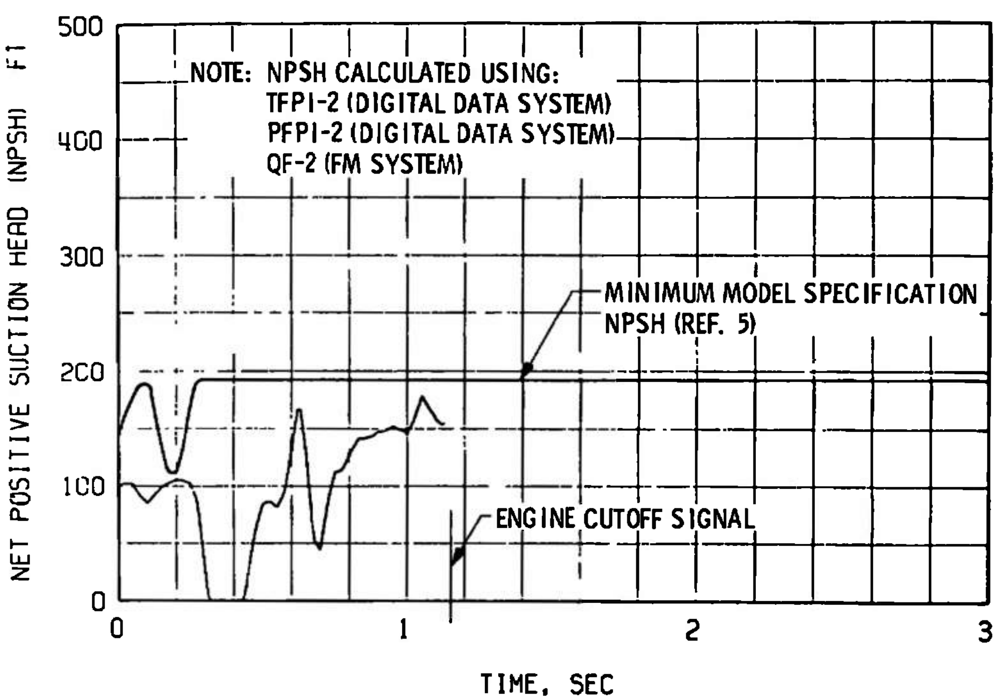


Fig. 88 Fuel Pump Start Transient Performance, Firing 32C

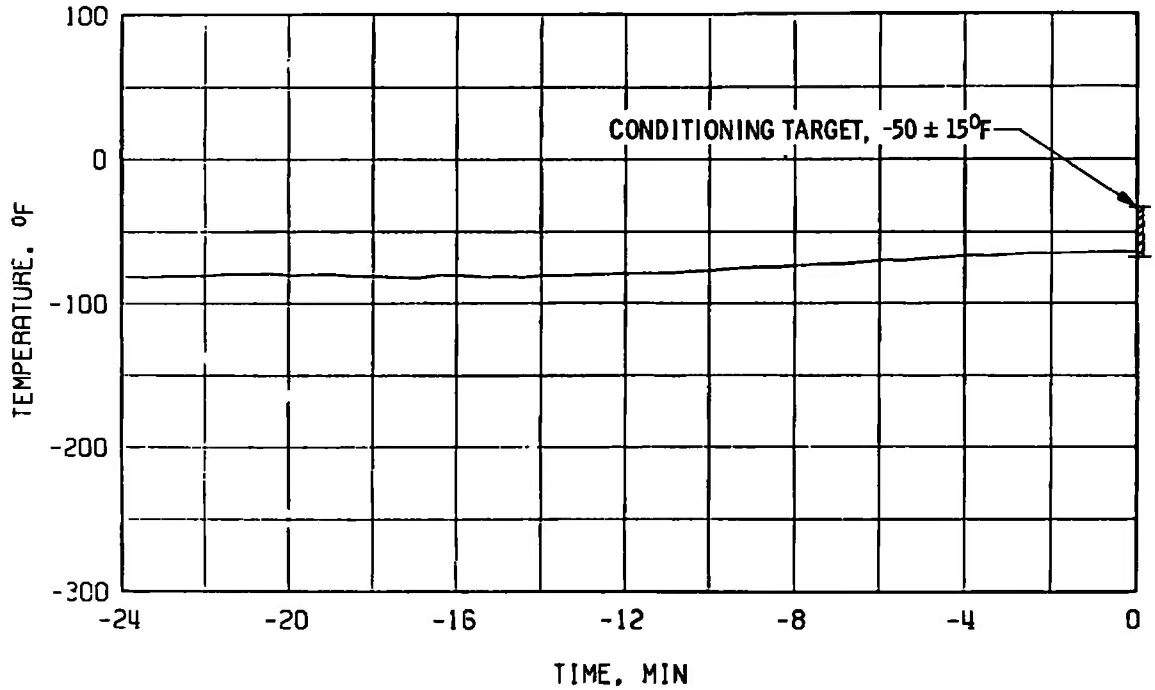


a. Duct Pressure and Temperature Transients

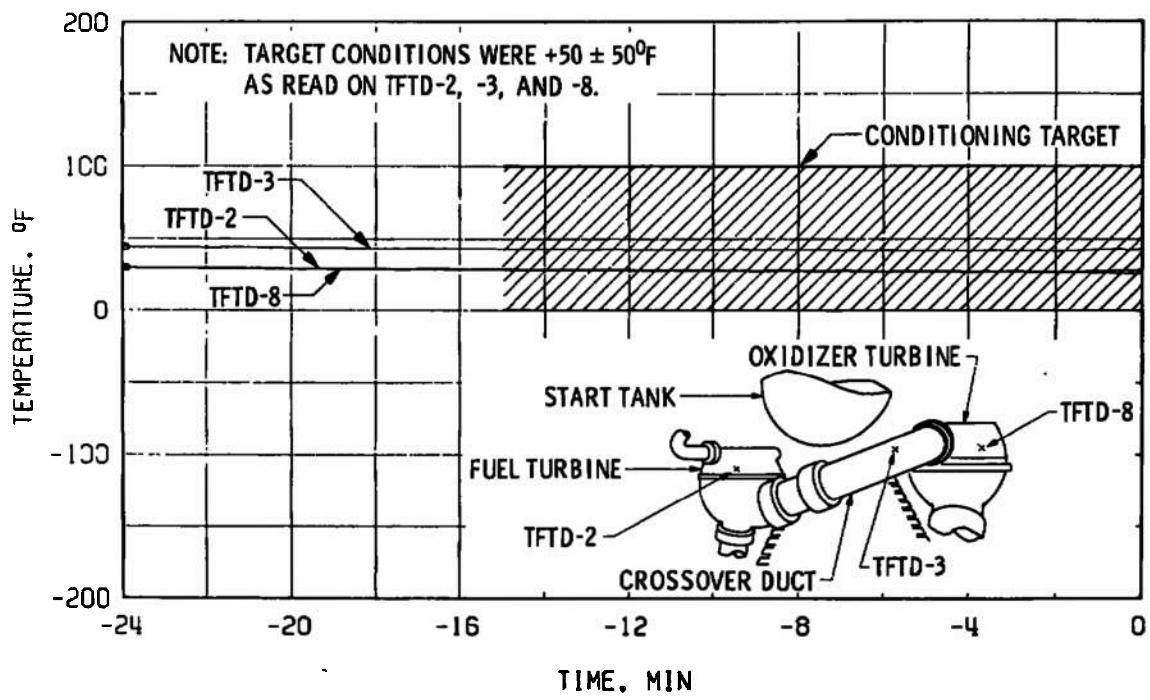


b. Fuel Pump NPSH during Start Transient, Firing 32C

Fig. 89 Fuel Low Pressure Duct Performance, Firing 32C

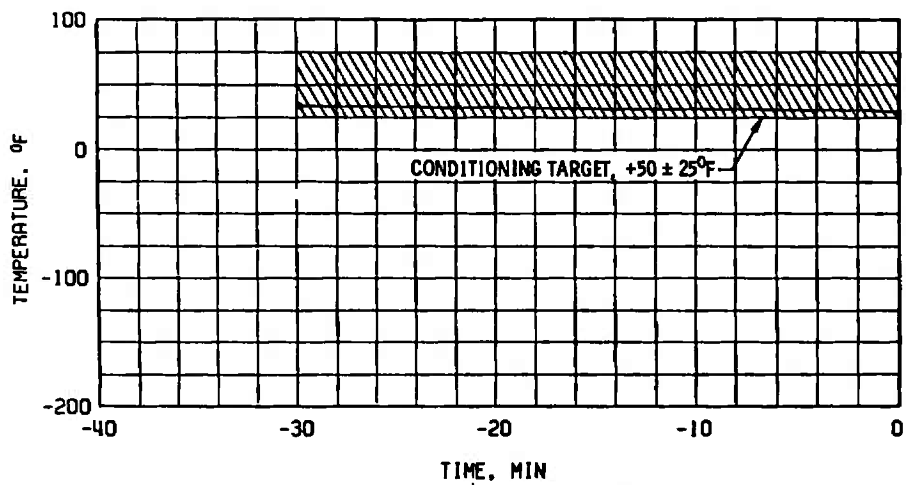


a. Thrust Chamber Throat, TTC-1P

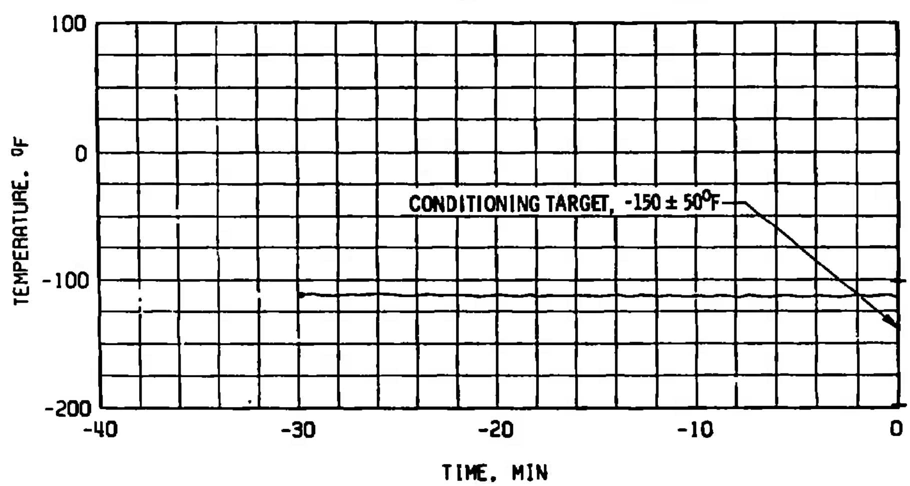


b. Crossover Duct, TFTD

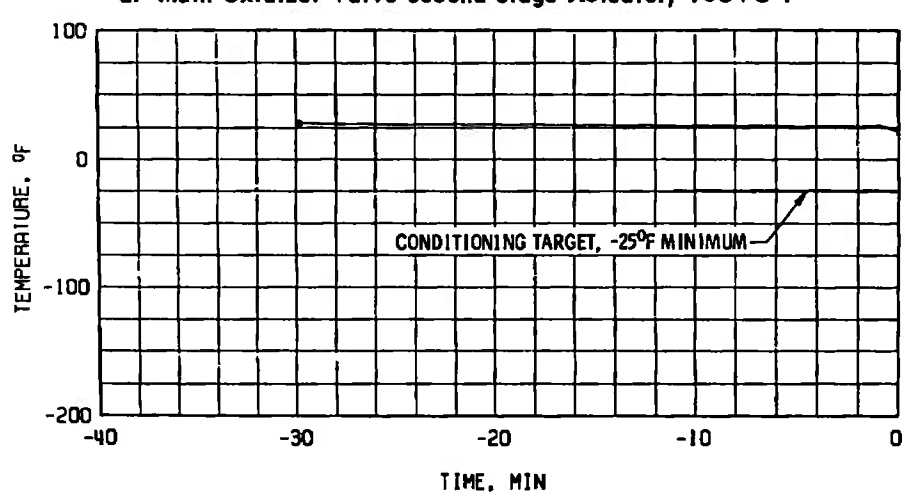
Fig. 90 Thermal Conditioning History of Engine Components, Firing 32D



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1



e. Gas Generator Body Temperature, TGGVRS

Fig. 90 Concluded

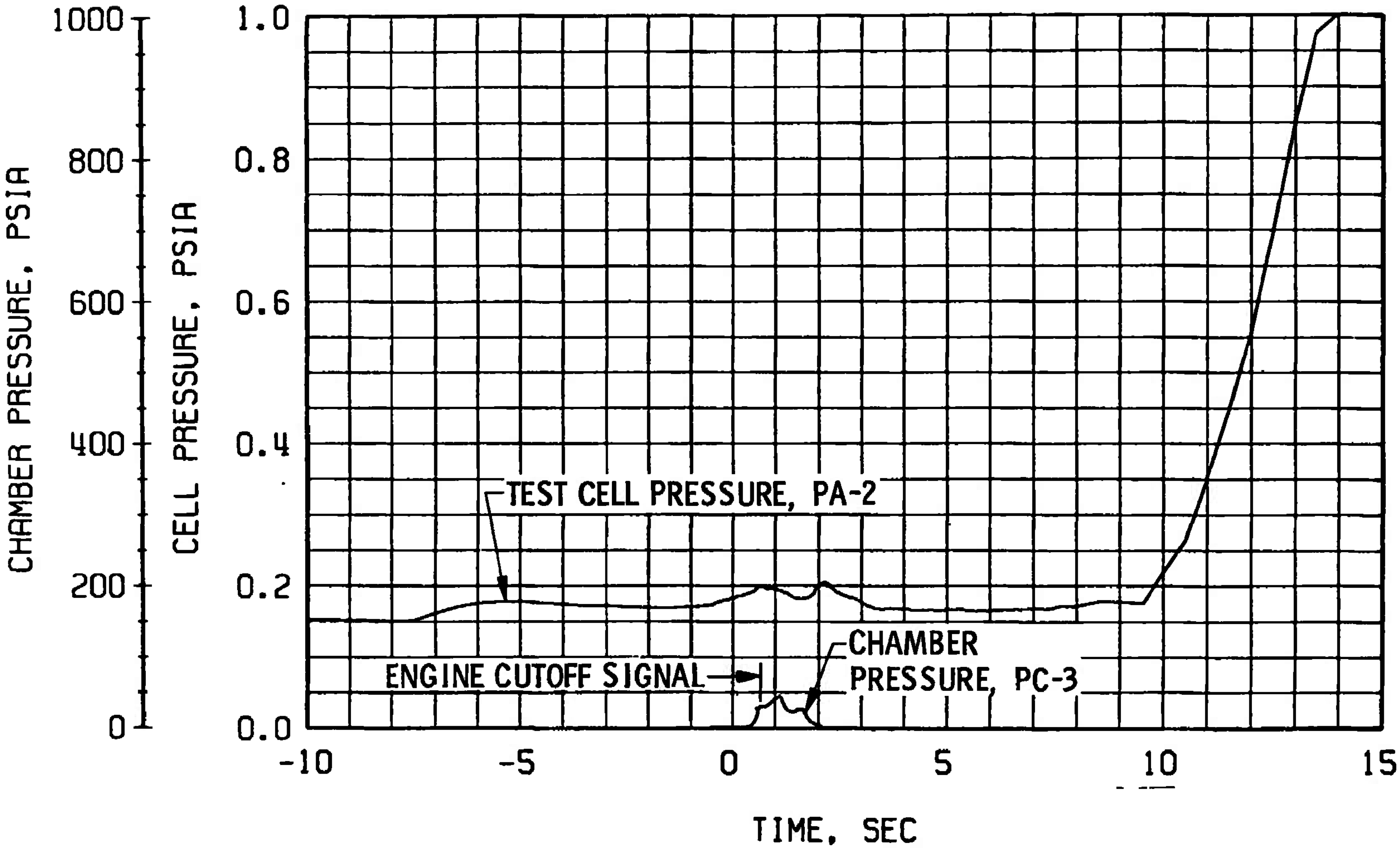
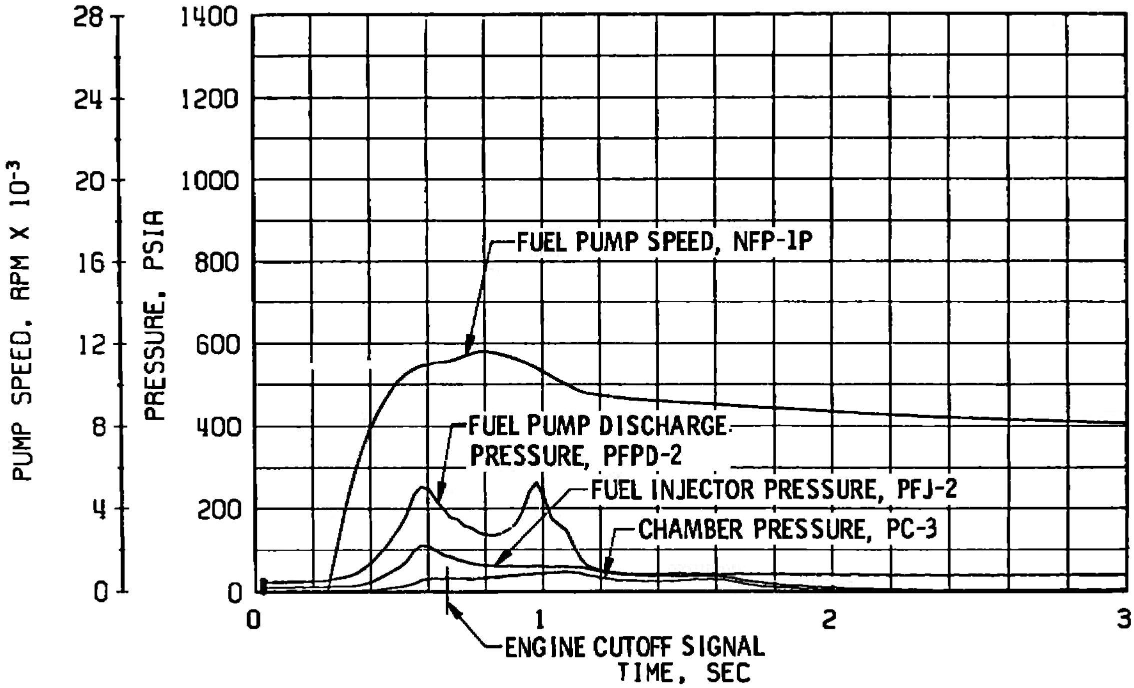
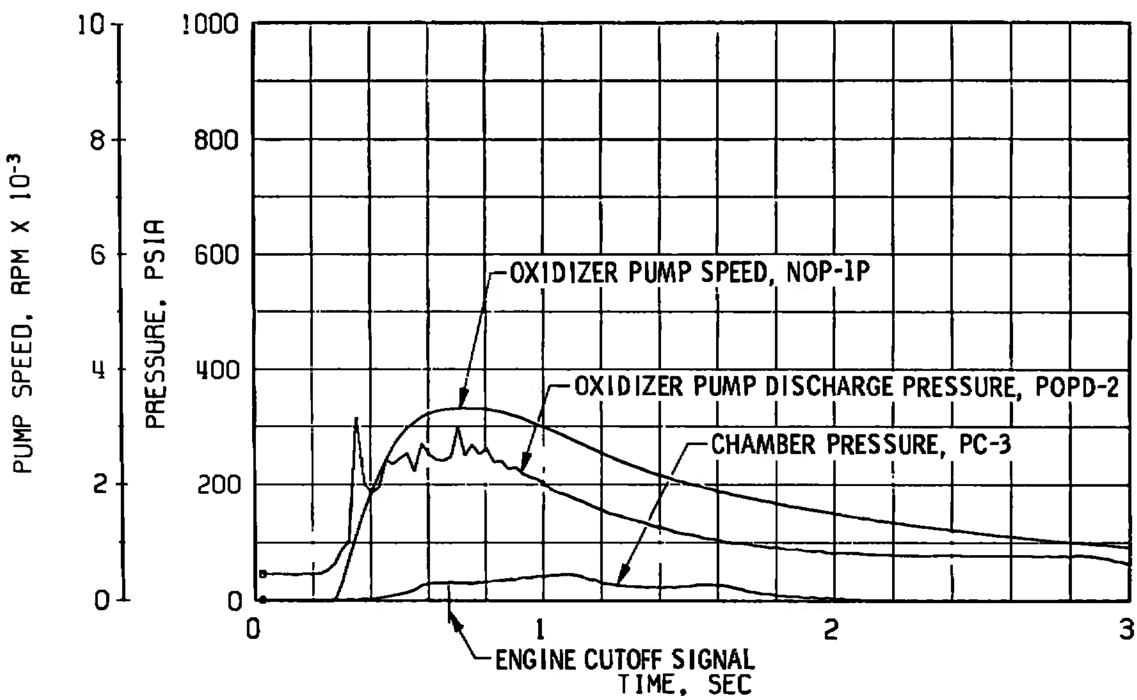


Fig. 91 Engine Ambient and Combustion Chamber Pressures, Firing 32D

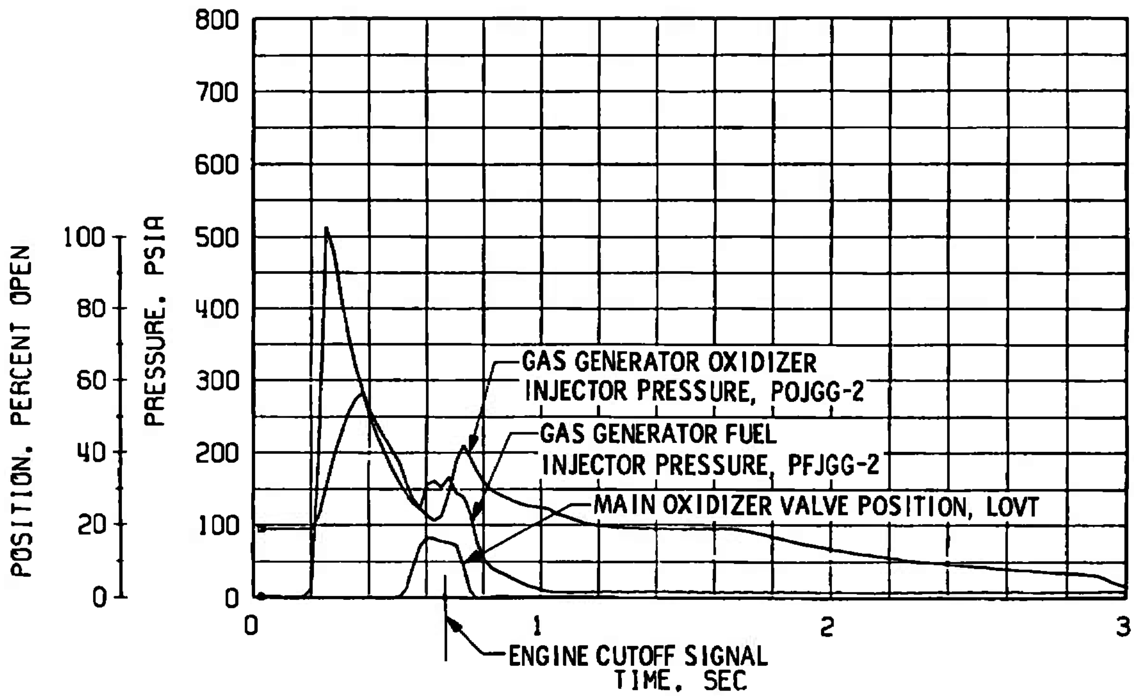


a. Thrust Chamber Fuel System, Start and Shutdown

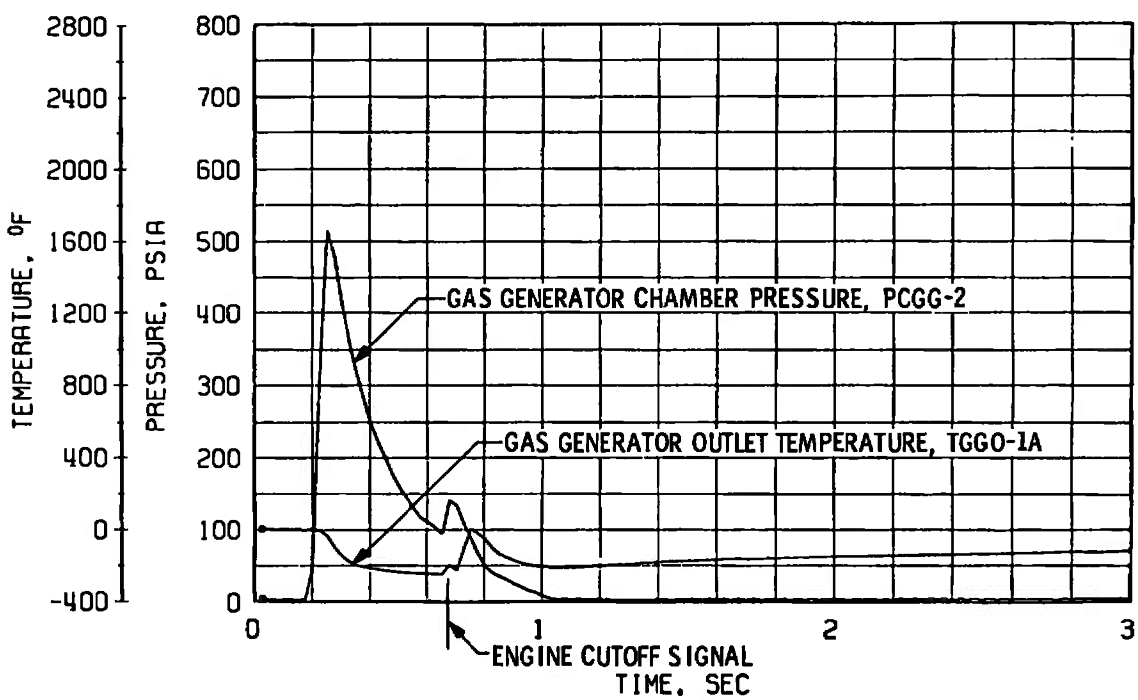


b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 92 Engine Transient Operation, Firing 32D



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 92 Concluded

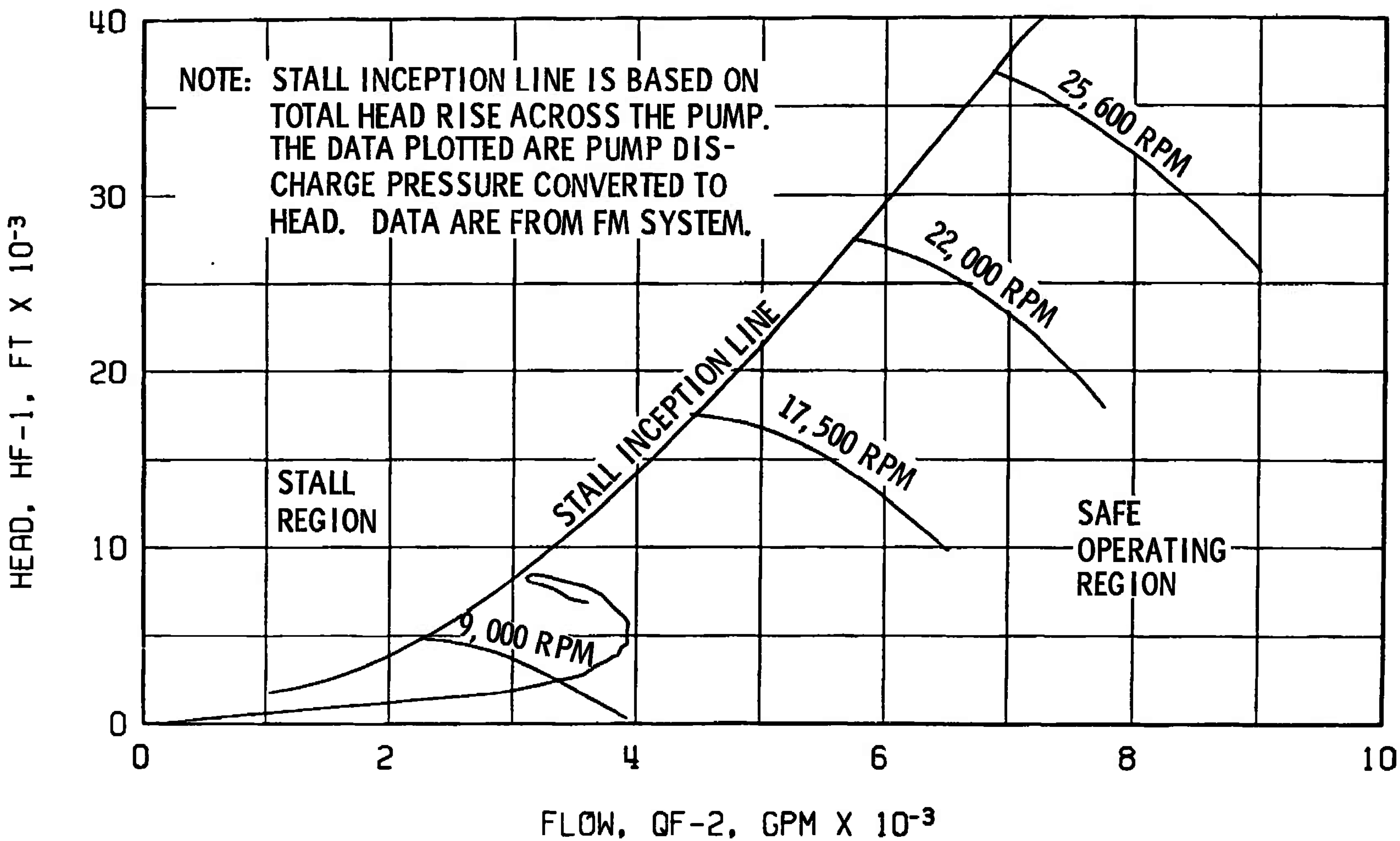
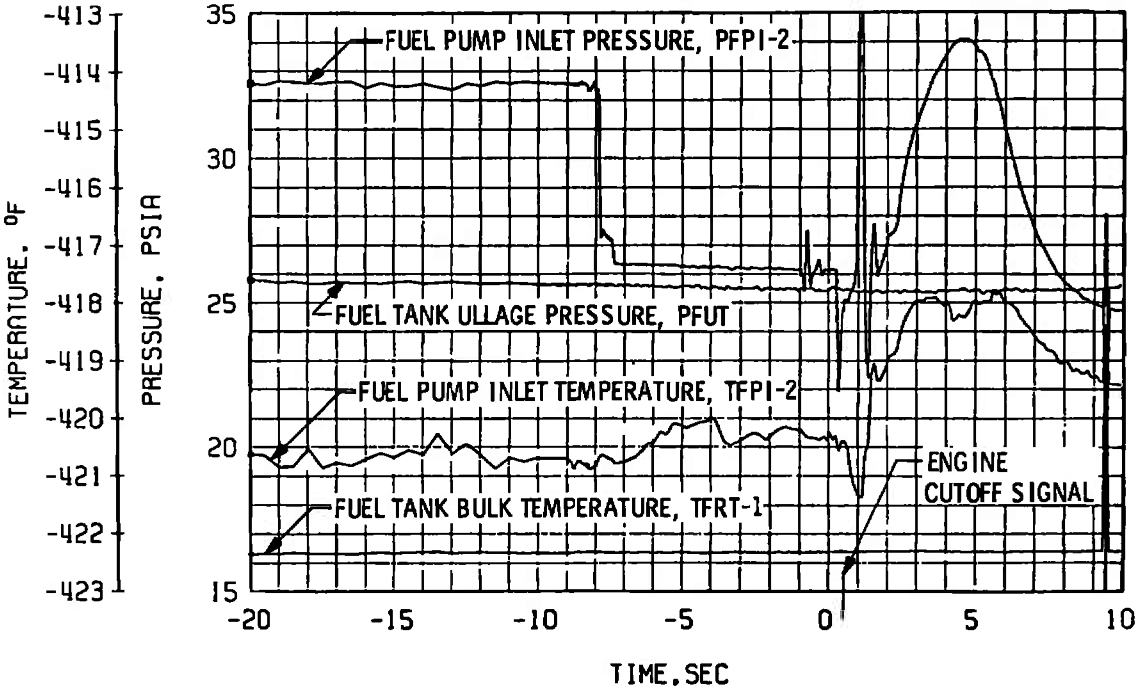
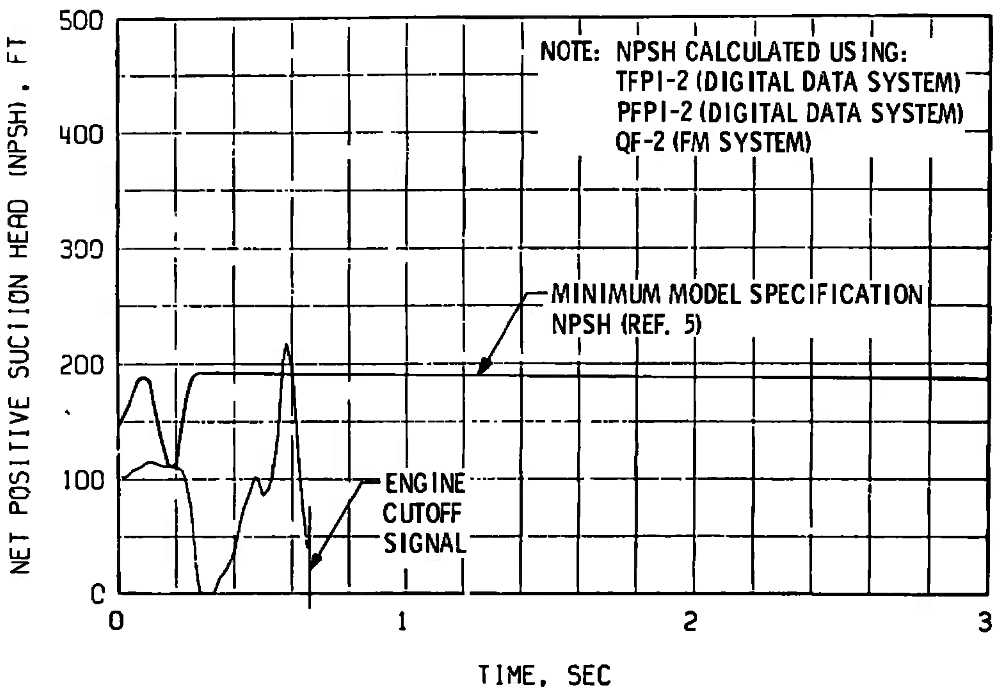


Fig. 93 Fuel Pump Start Transient Performance, Firing 32D

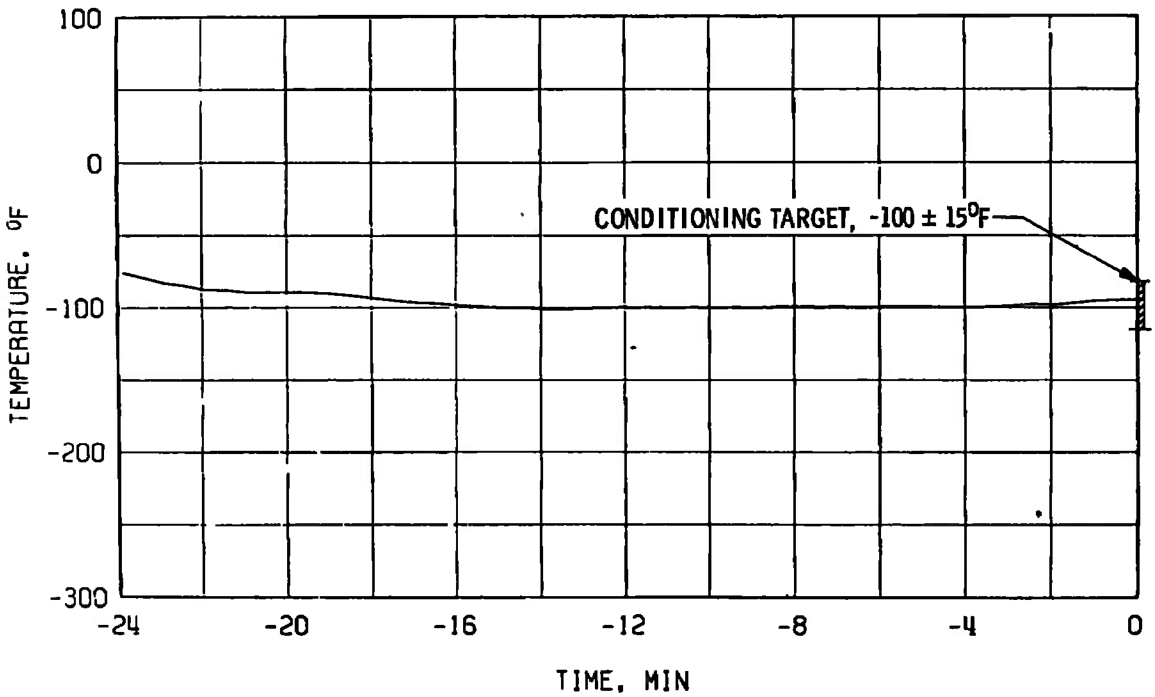


a. Duct Pressure and Temperature Transients

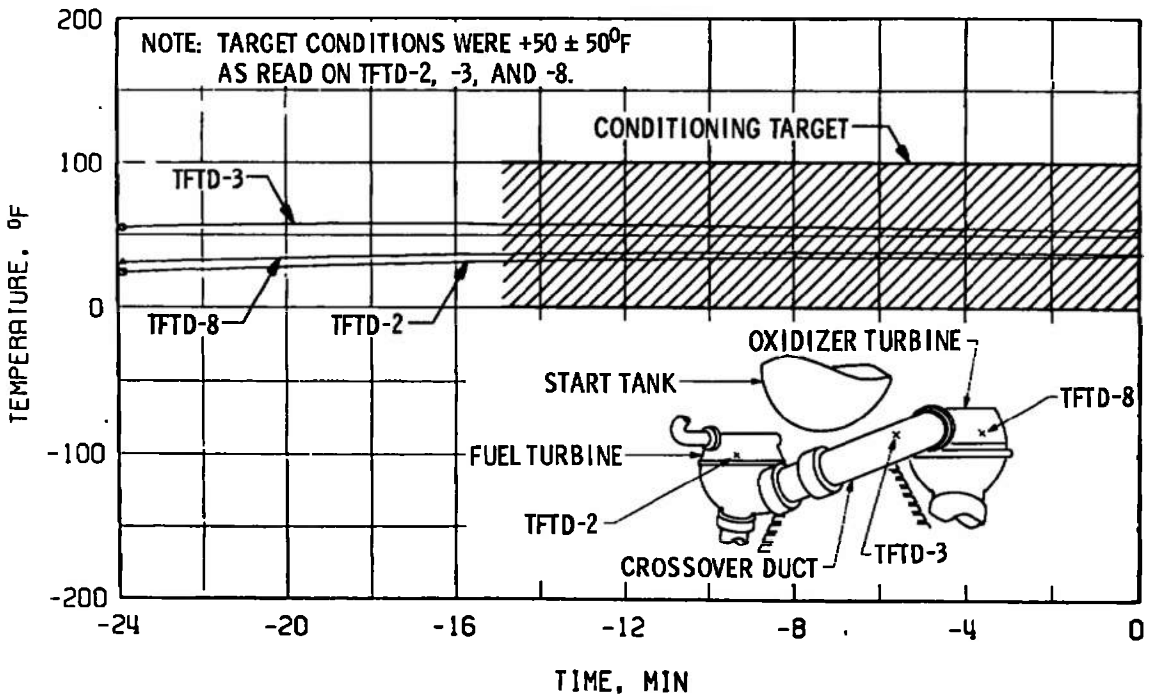


b. Fuel Pump NPSH during Start Transient, Firing 32D

Fig. 94 Fuel Low Pressure Duct Performance, Firing 32D

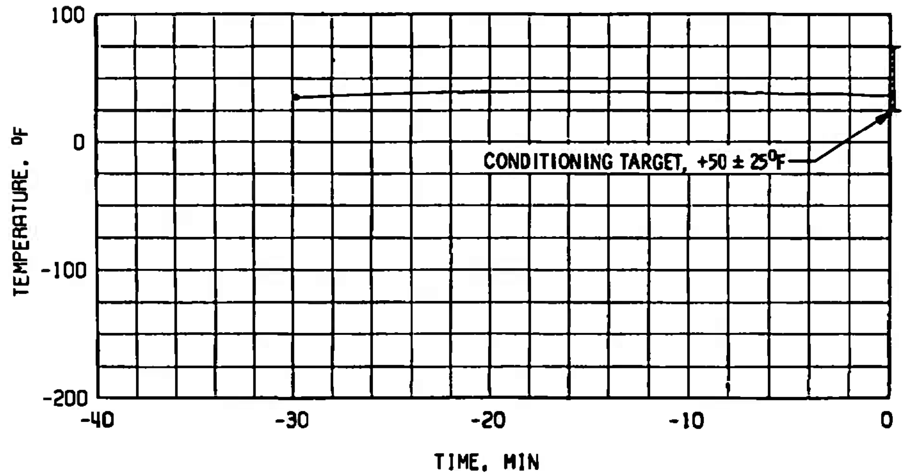


a. Thrust Chamber Throat, TTC-1P

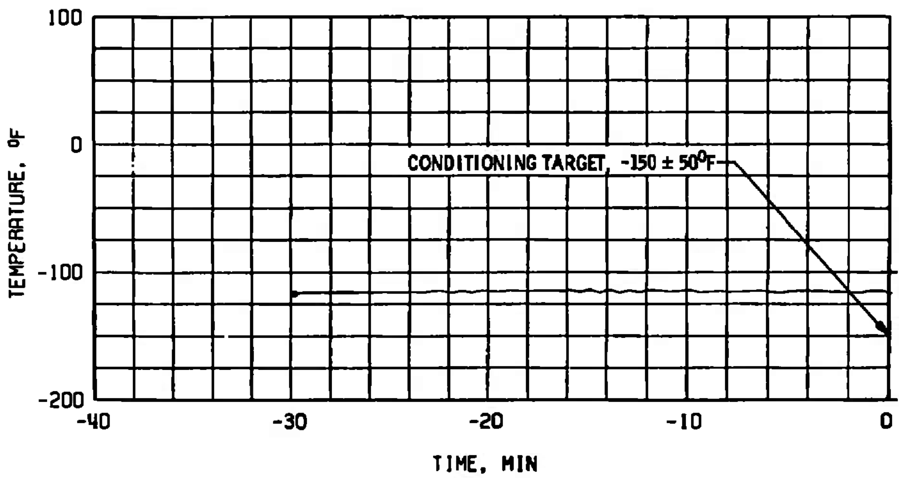


b. Crossover Duct, TFTD

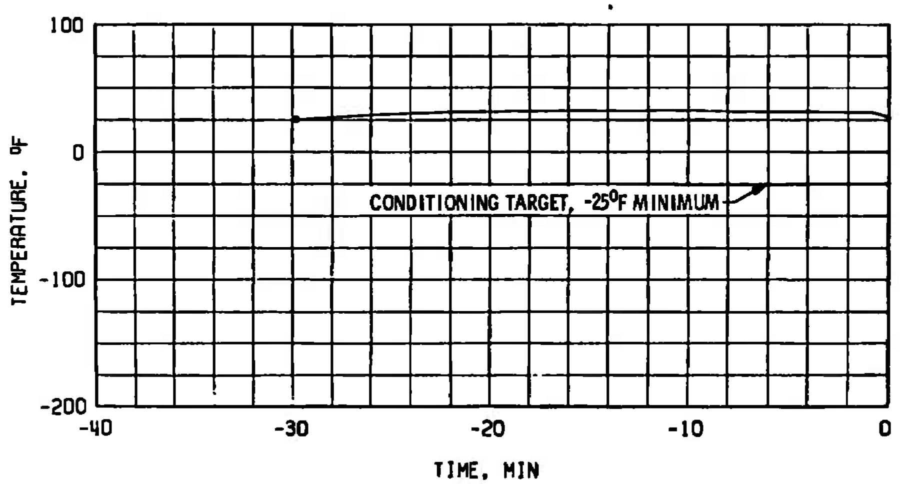
Fig. 95 Thermal Conditioning History of Engine Components, Firing 32E



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1



e. Gas Generator Valve Body, TGGVRS

Fig. 95 Concluded

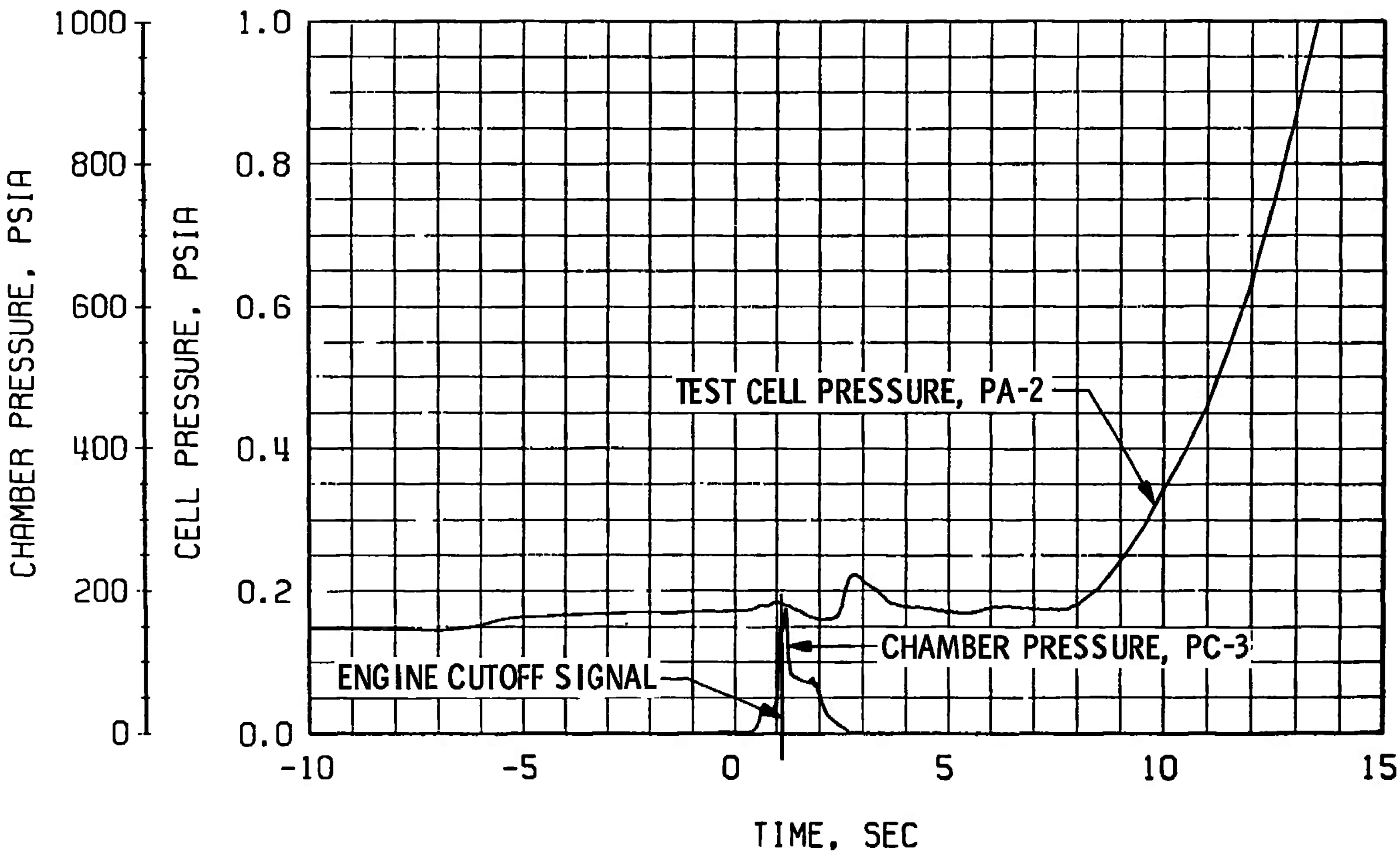
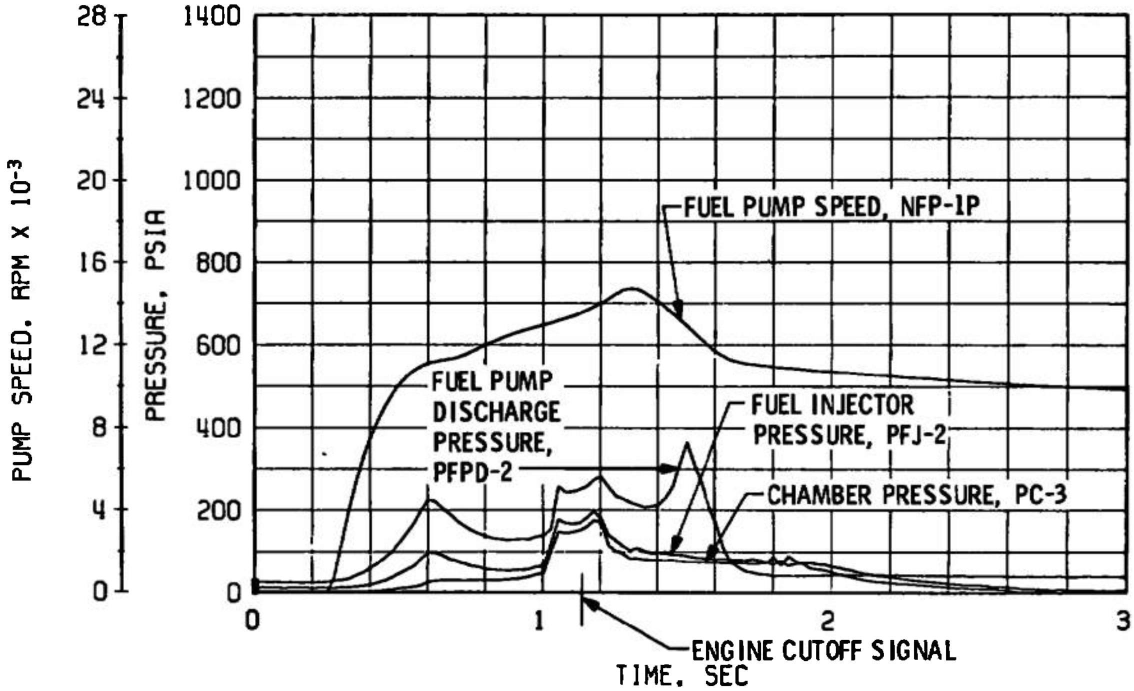
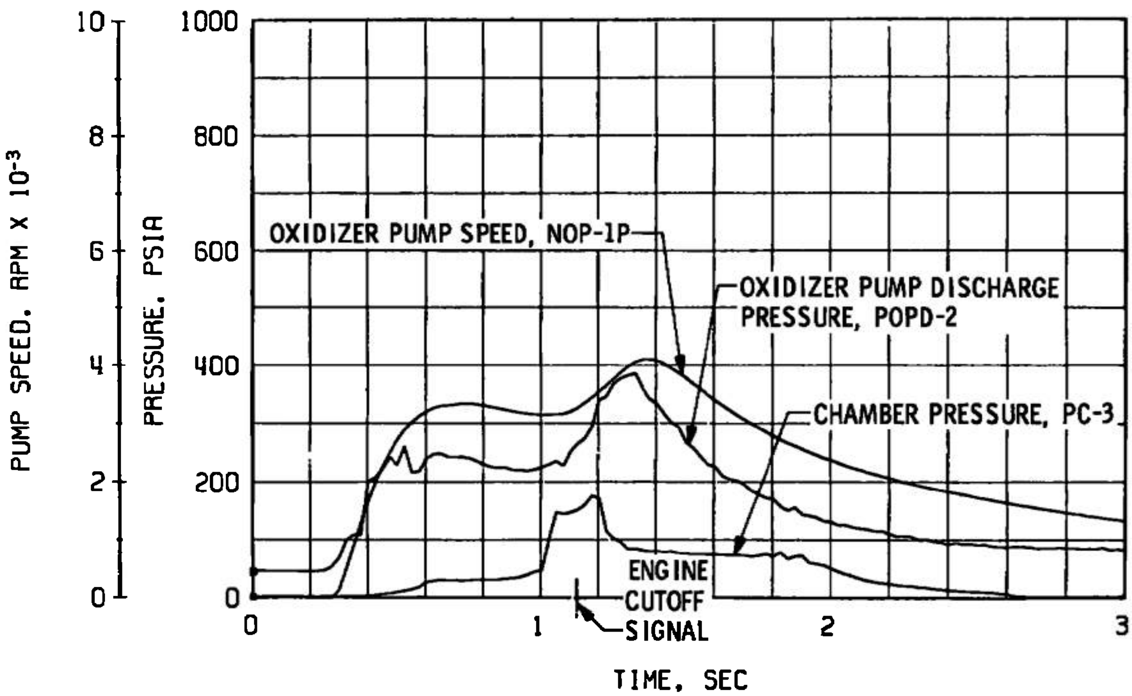


Fig. 96 Engine Ambient and Combustion Chamber Pressures, Firing 32E

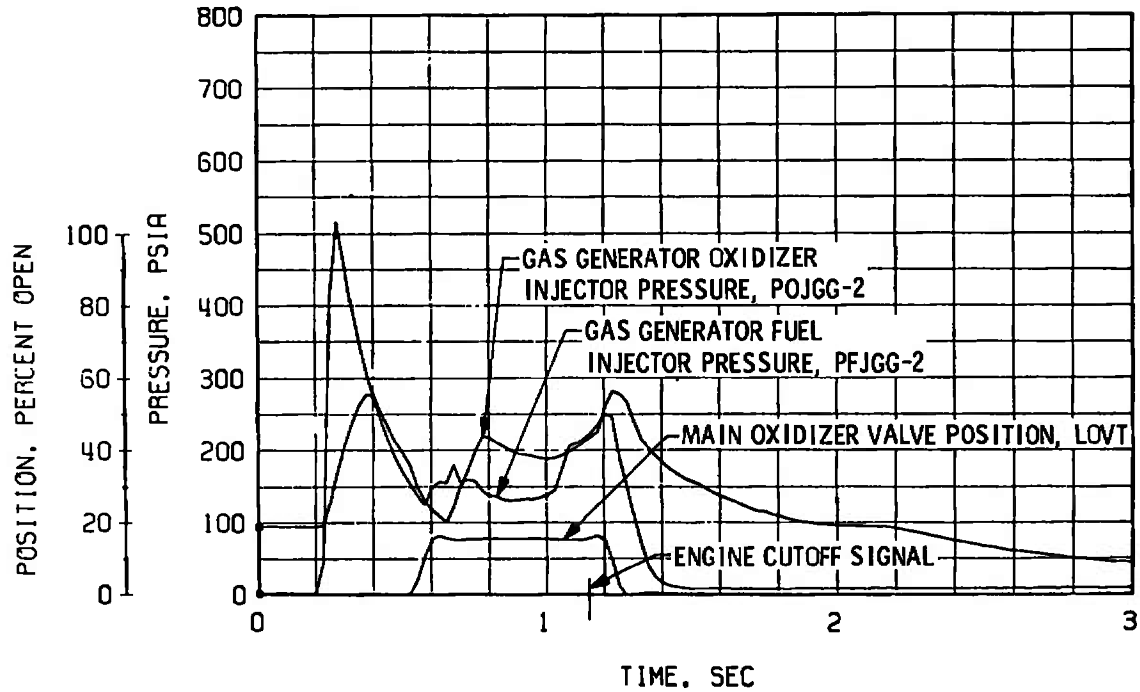


a. Thrust Chamber Fuel System, Start and Shutdown

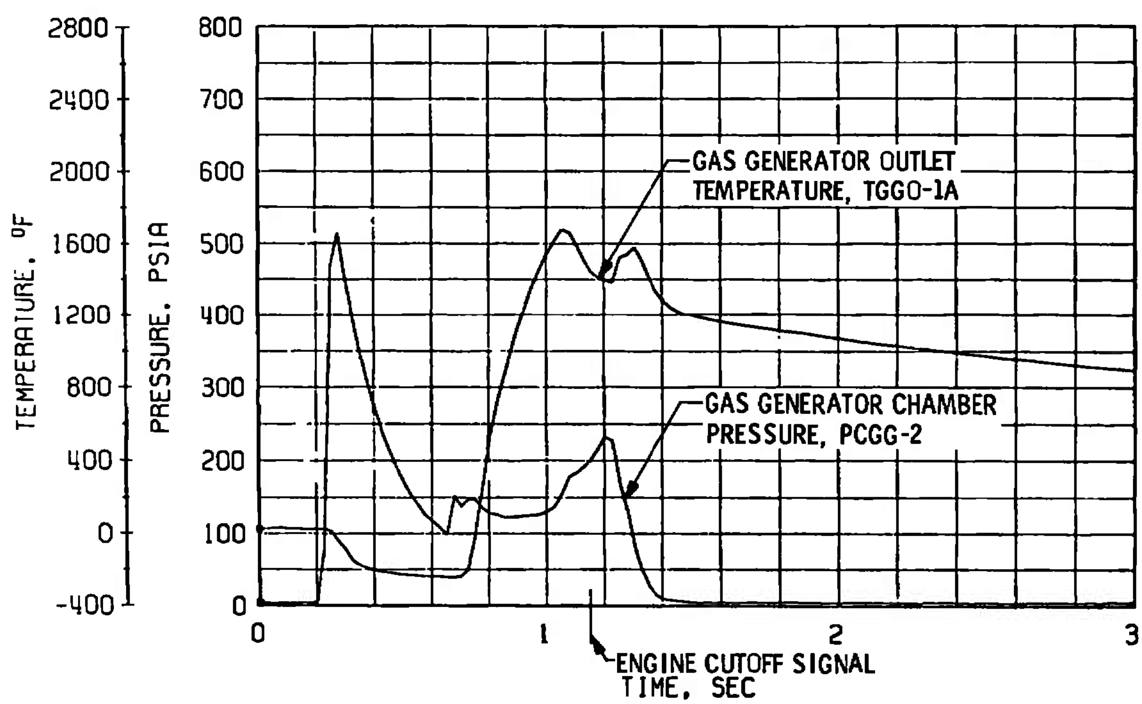


b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 97 Engine Transient Operation, Firing 32E



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 97 Concluded

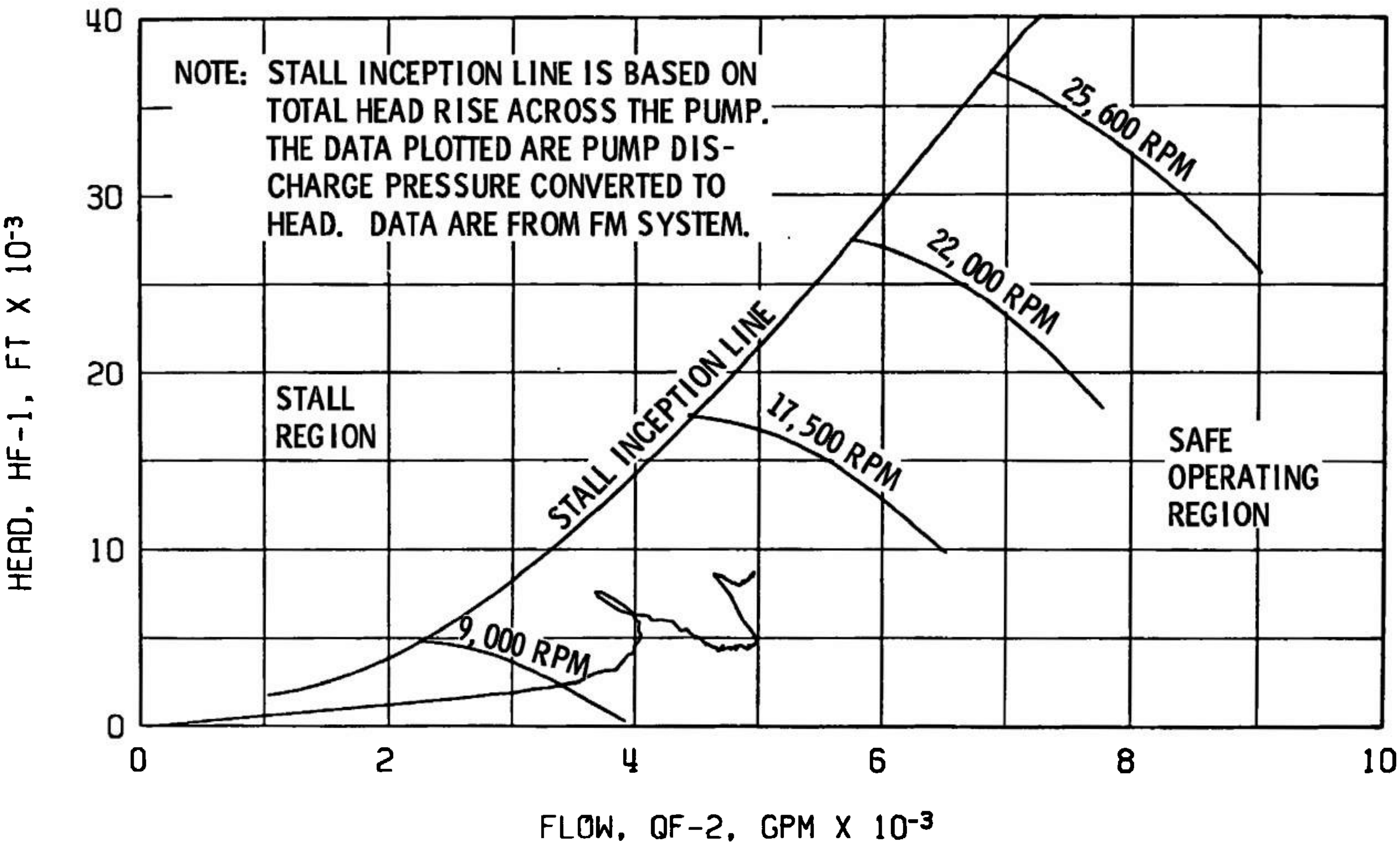
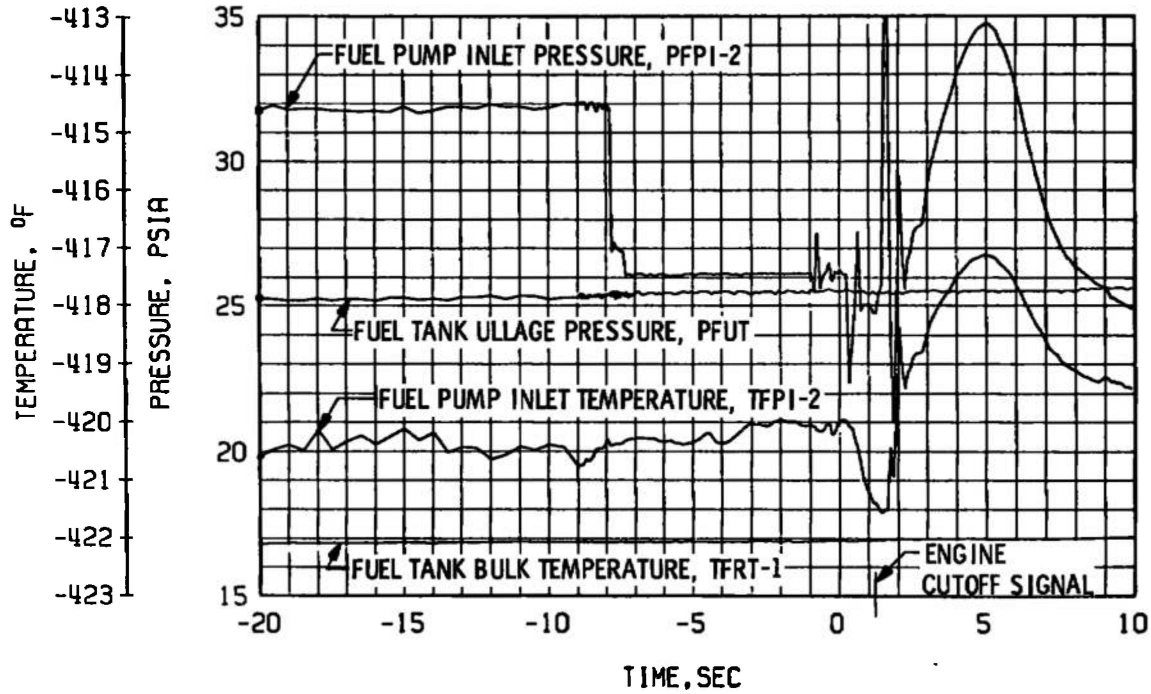
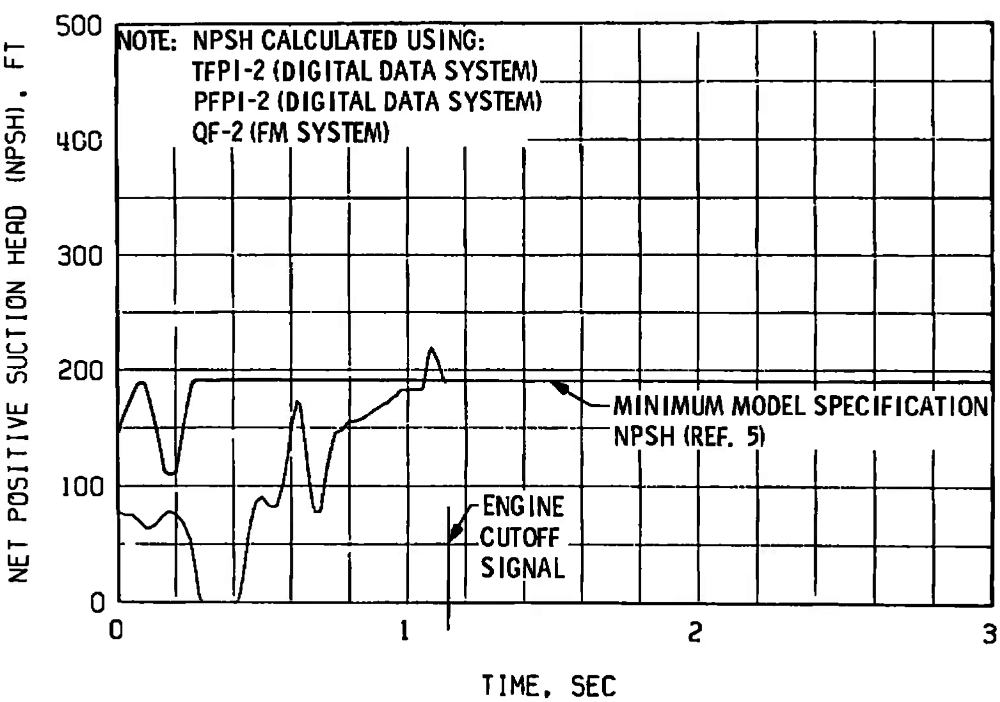


Fig. 98 Fuel Pump Start Transient Performance, Firing 32E

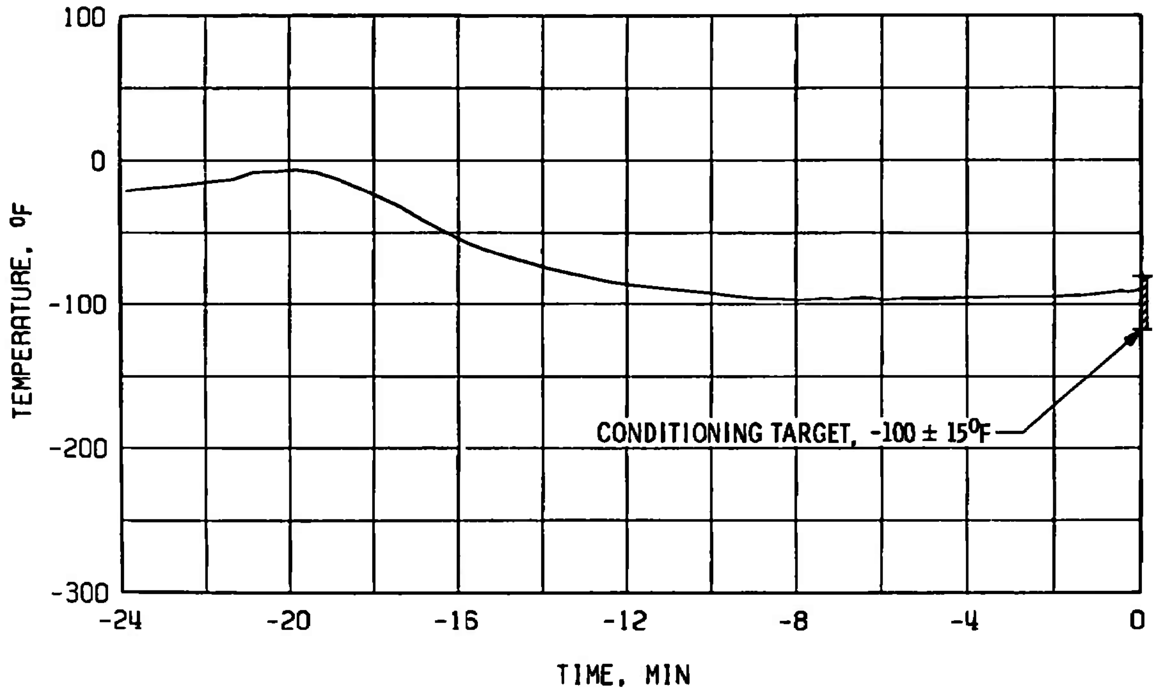


a. Duct Pressure and Temperature Transients

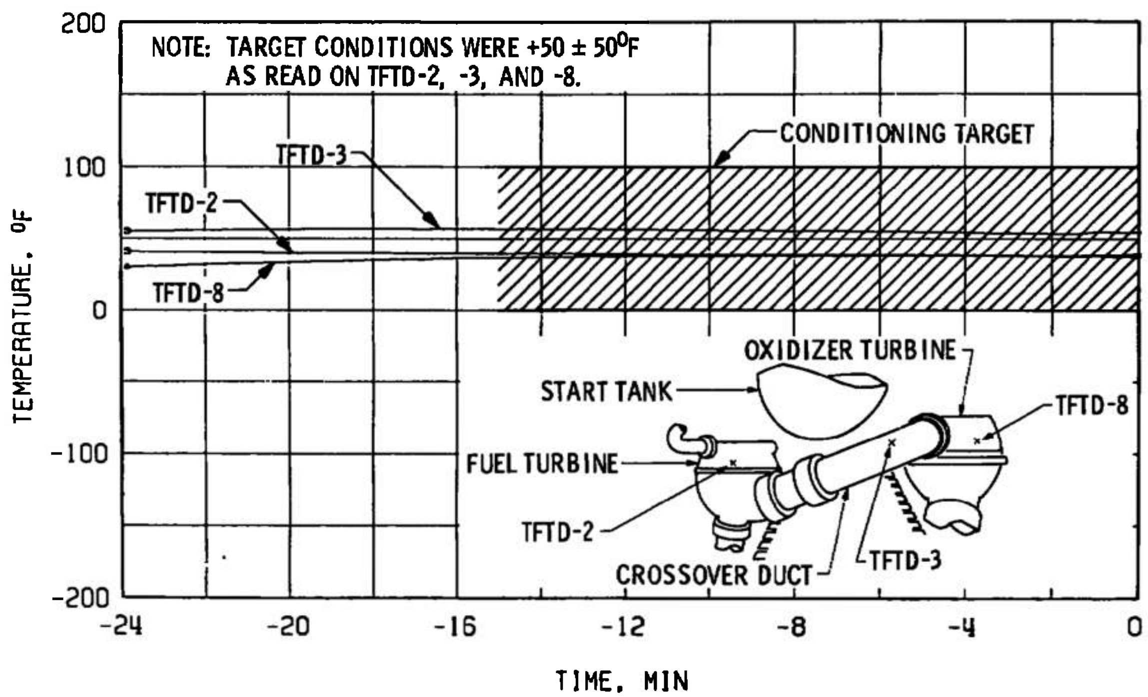


b. Fuel Pump NPSH during Start Transient, Firing 32E

Fig. 99 Fuel Low Pressure Duct Performance, Firing 32E

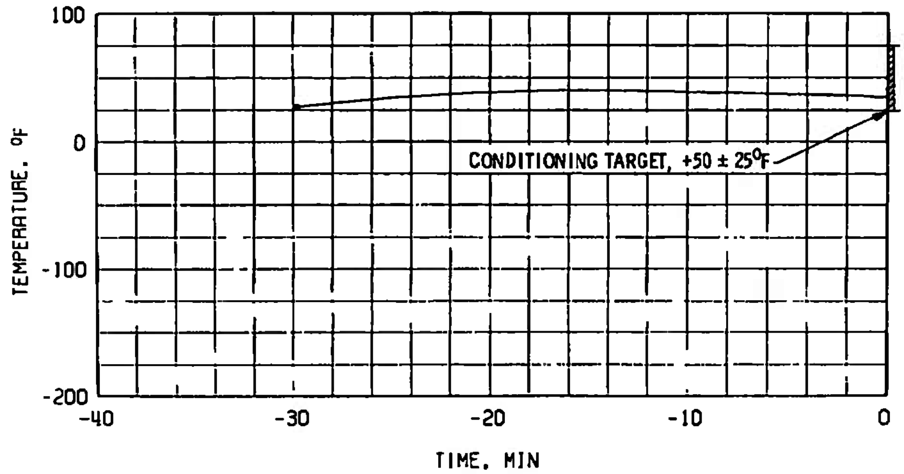


a. Thrust Chamber Throat, TTC-1P

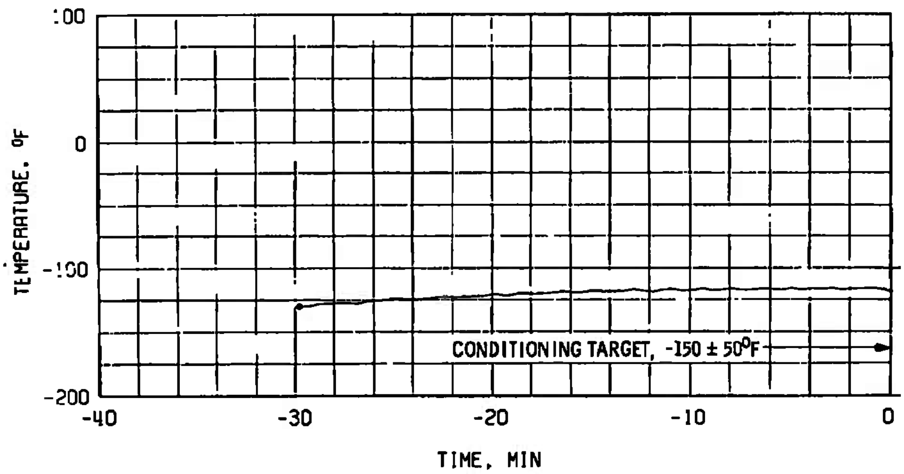


b. Crossover Duct, TFTD

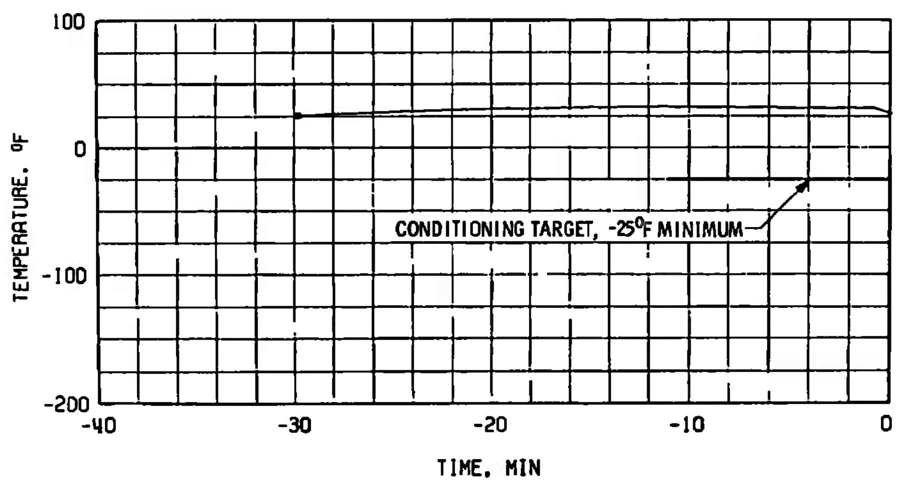
Fig. 100 Thermal Conditioning History of Engine Components, Firing 32F



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1



e. Gas Generator Body Temperature, TGGVRS

Fig. 100 Concluded

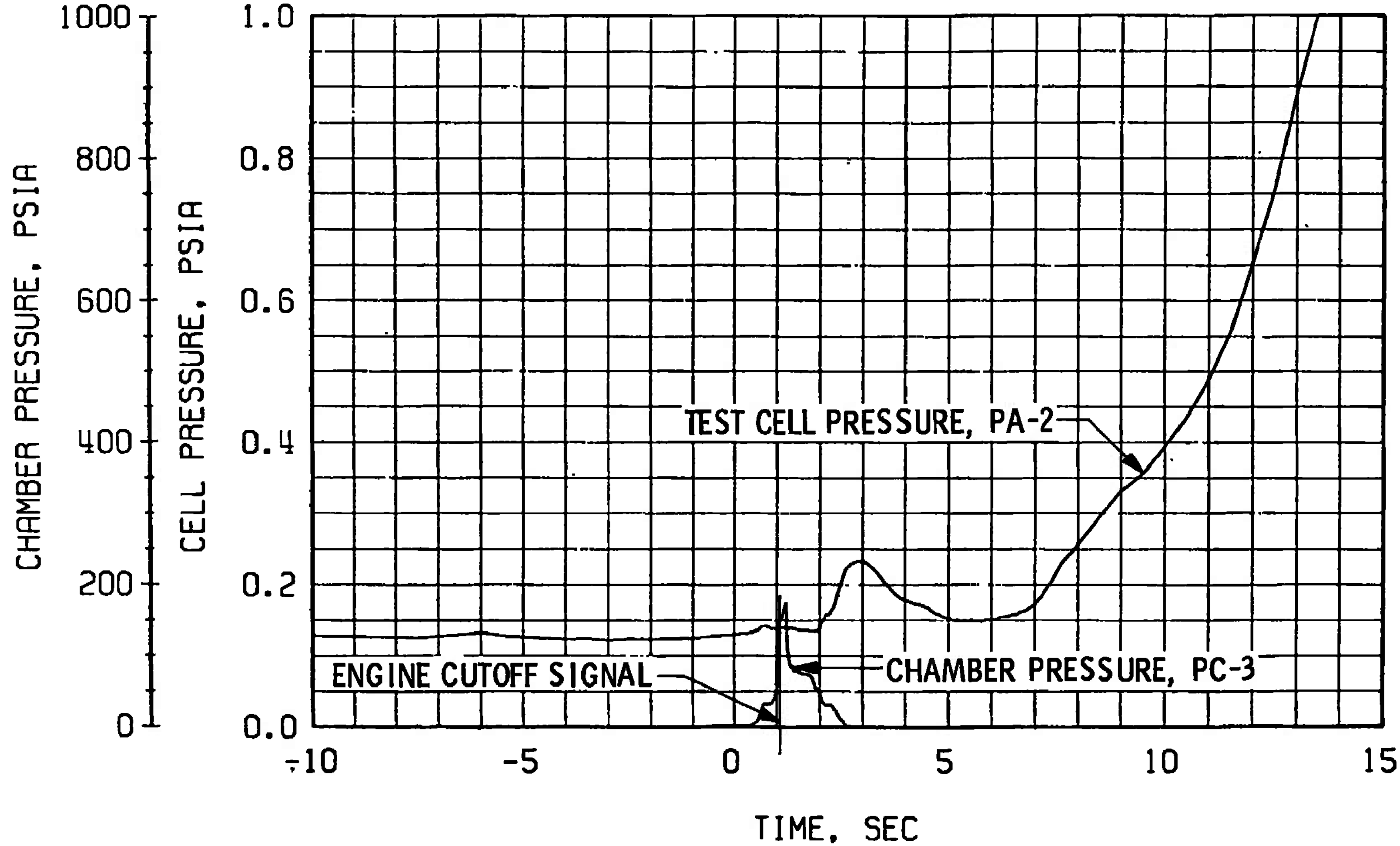
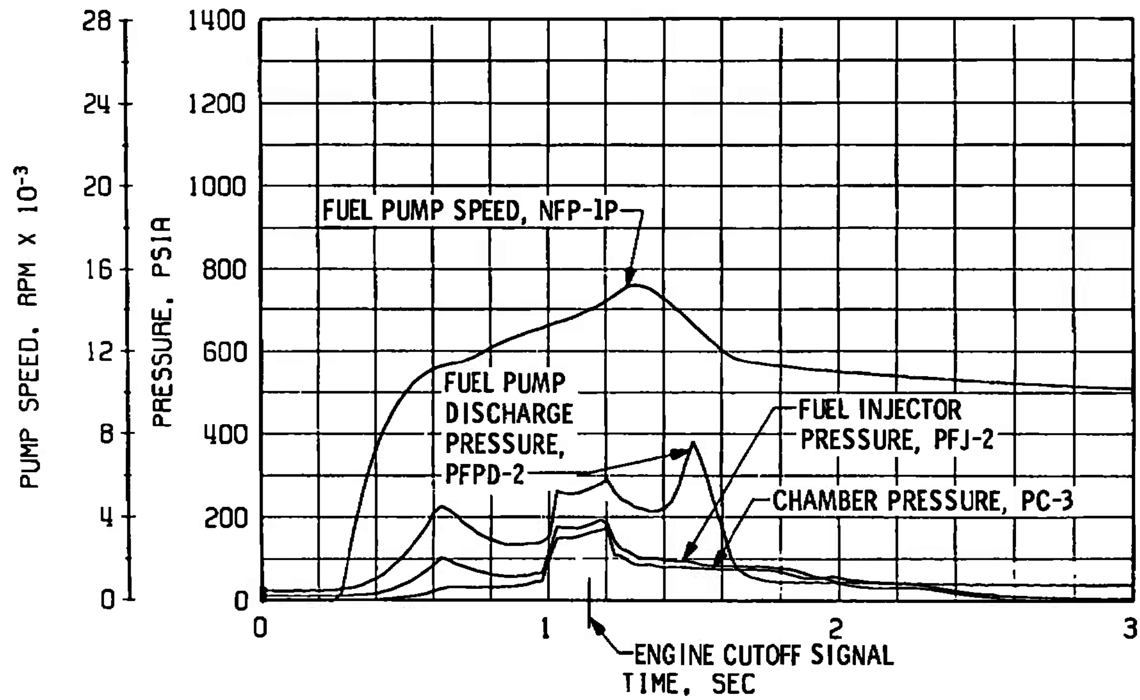
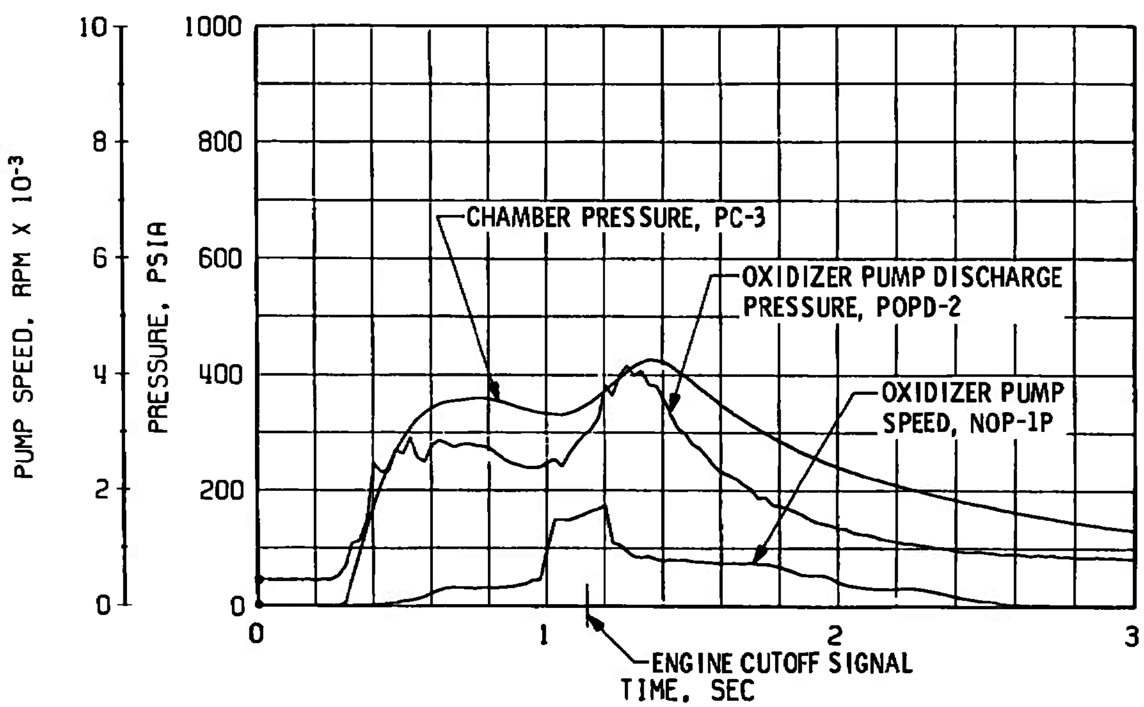


Fig. 101 Engine Ambient and Combustion Chamber Pressures, Firing 32F

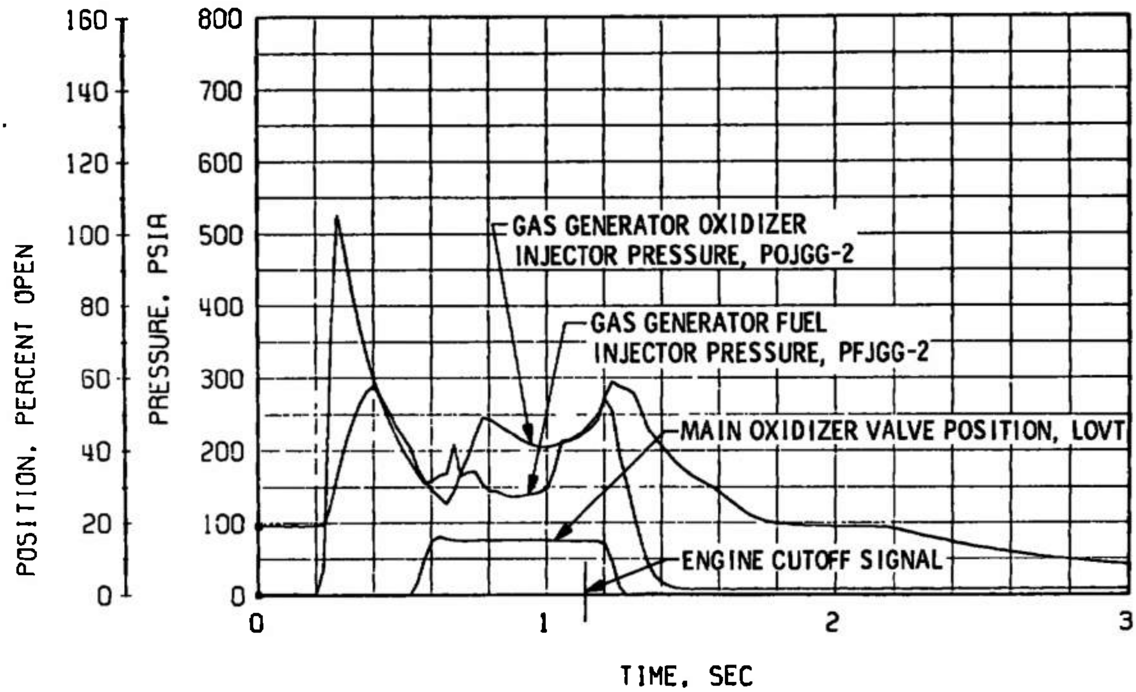


a. Thrust Chamber Fuel System, Start and Shutdown

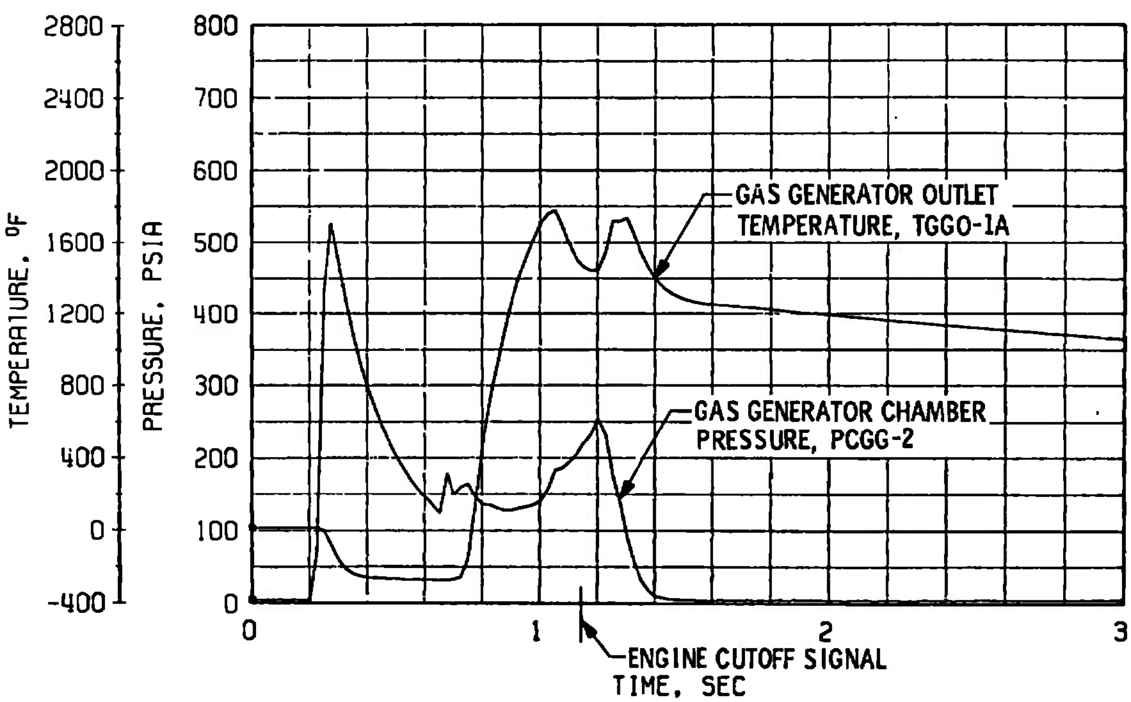


b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 102 Engine Transient Operation, Firing 32F



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 102 Concluded

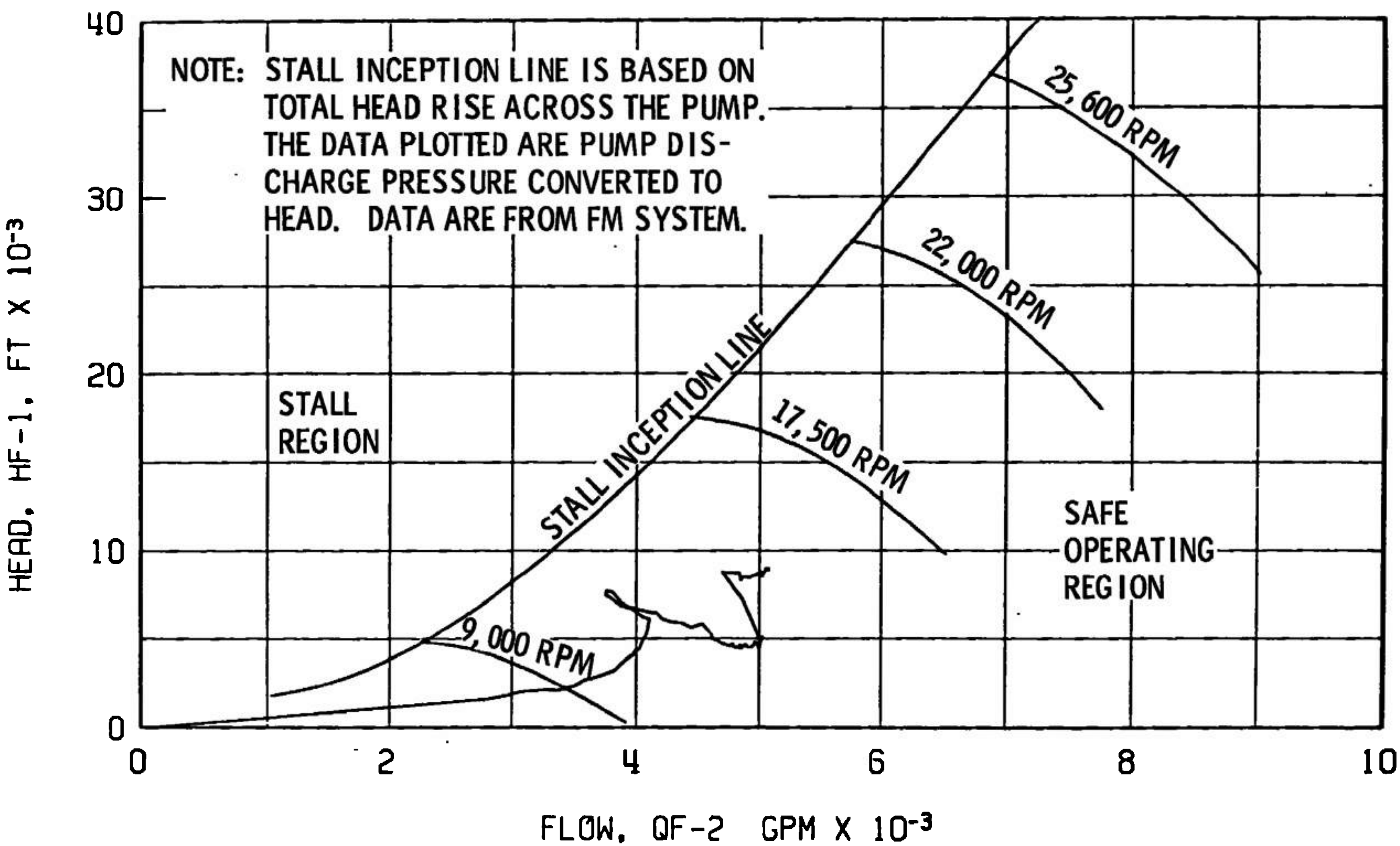
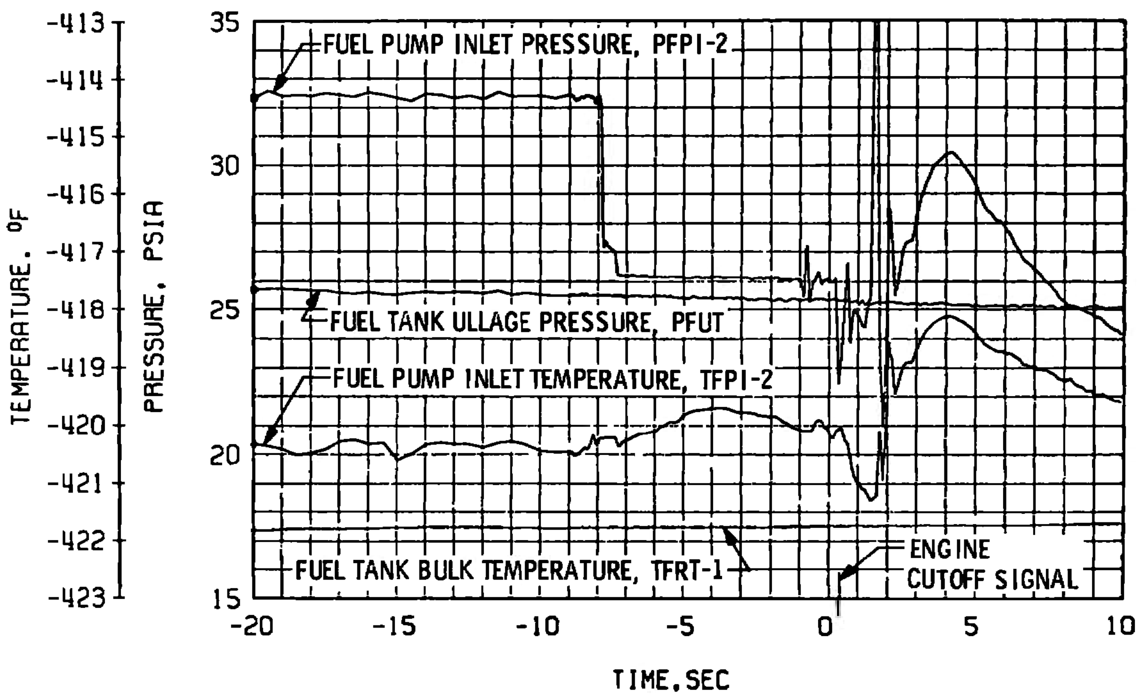
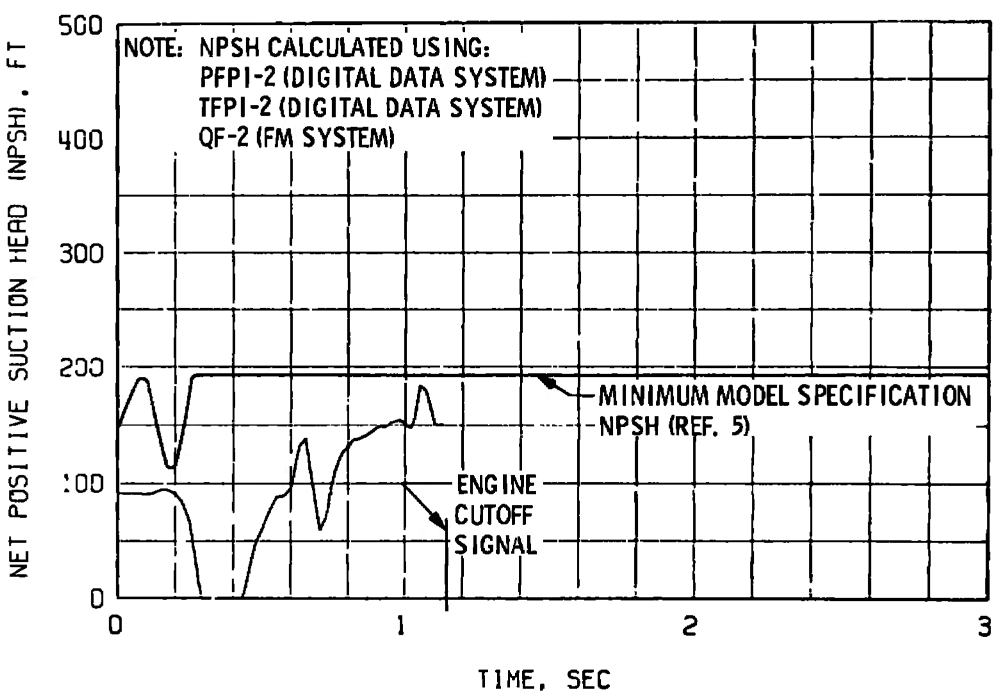


Fig. 103 Fuel Pump Start Transient Performance, Firing 32F

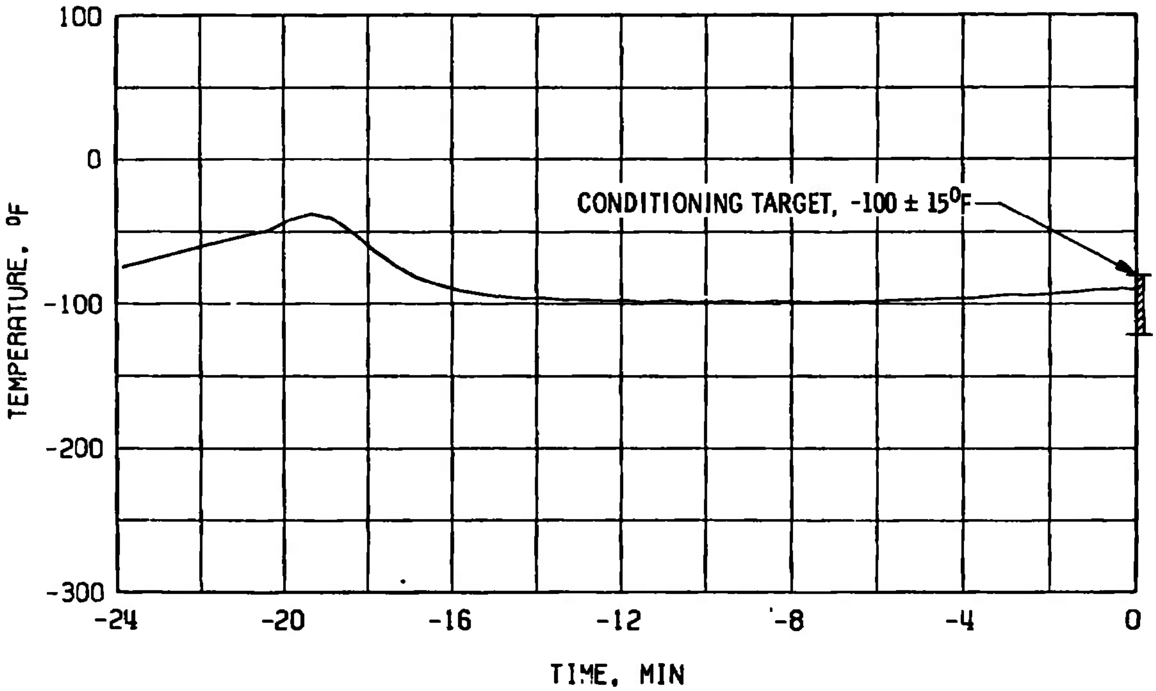


a. Duct Pressure and Temperature Transients

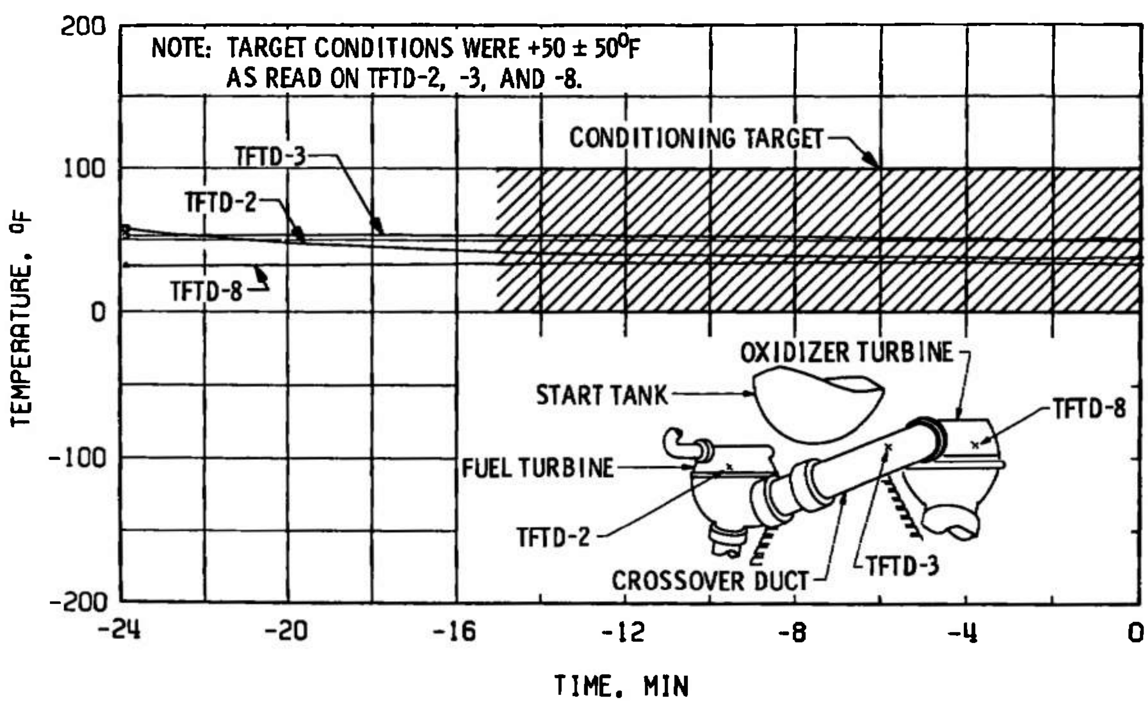


b. Fuel Pump NPSH during Start Transient, Firing 32F

Fig. 104 Fuel Low Pressure Duct Performance, Firing 32F

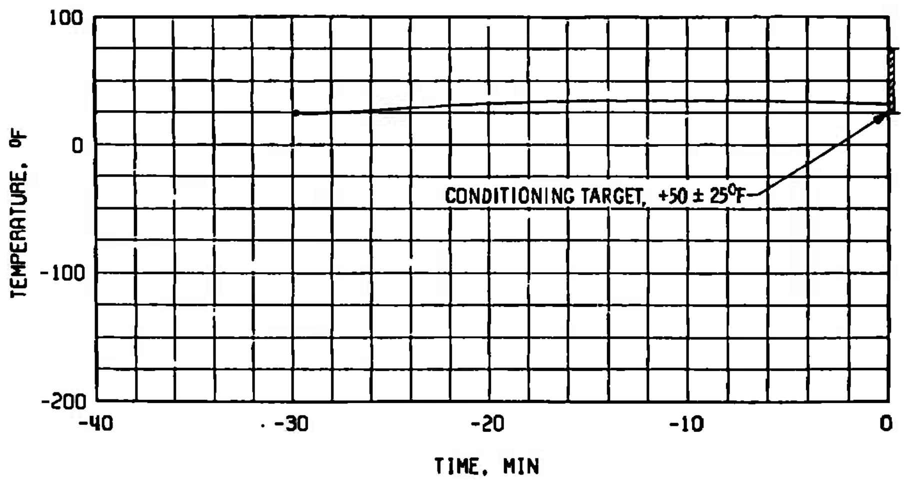


a. Thrust Chamber Throat, TTC-1P

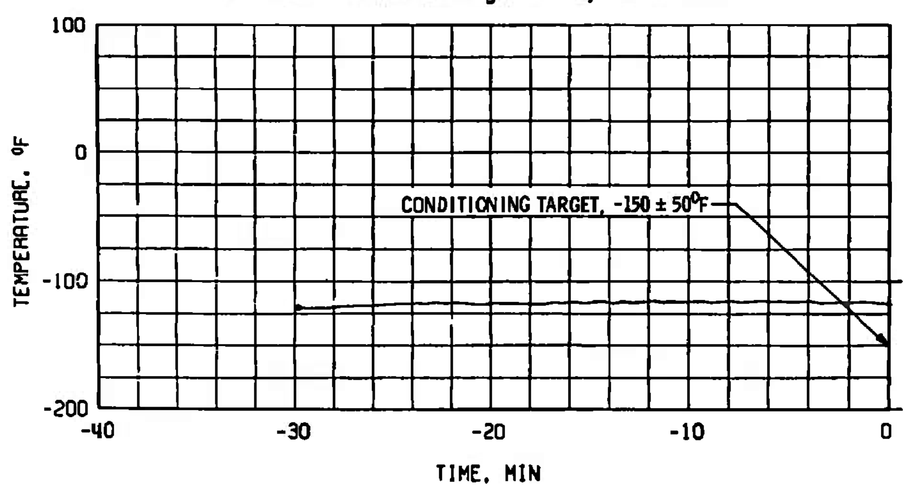


b. Crossover Duct, TFTD

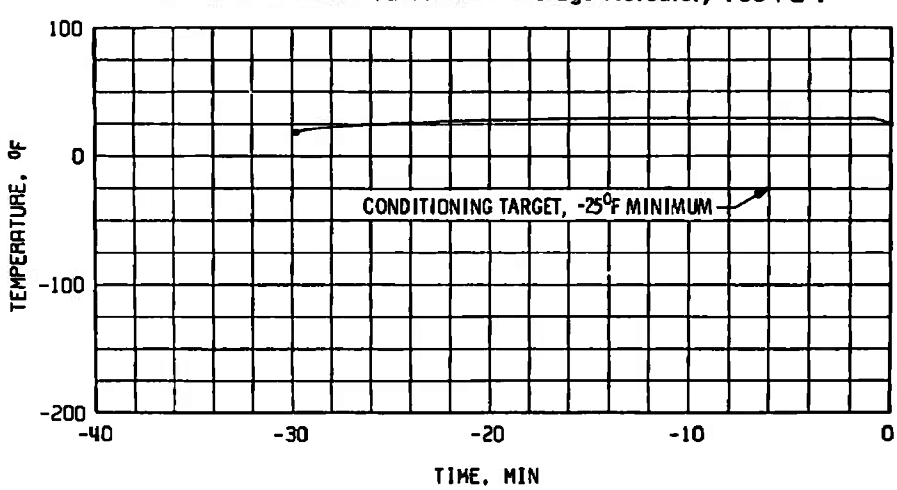
Fig. 105 Thermal Conditioning History of Engine Components, Firing 32G



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1



e. Gas Generator Body Temperature, TGGVRS

Fig. 105 Concluded

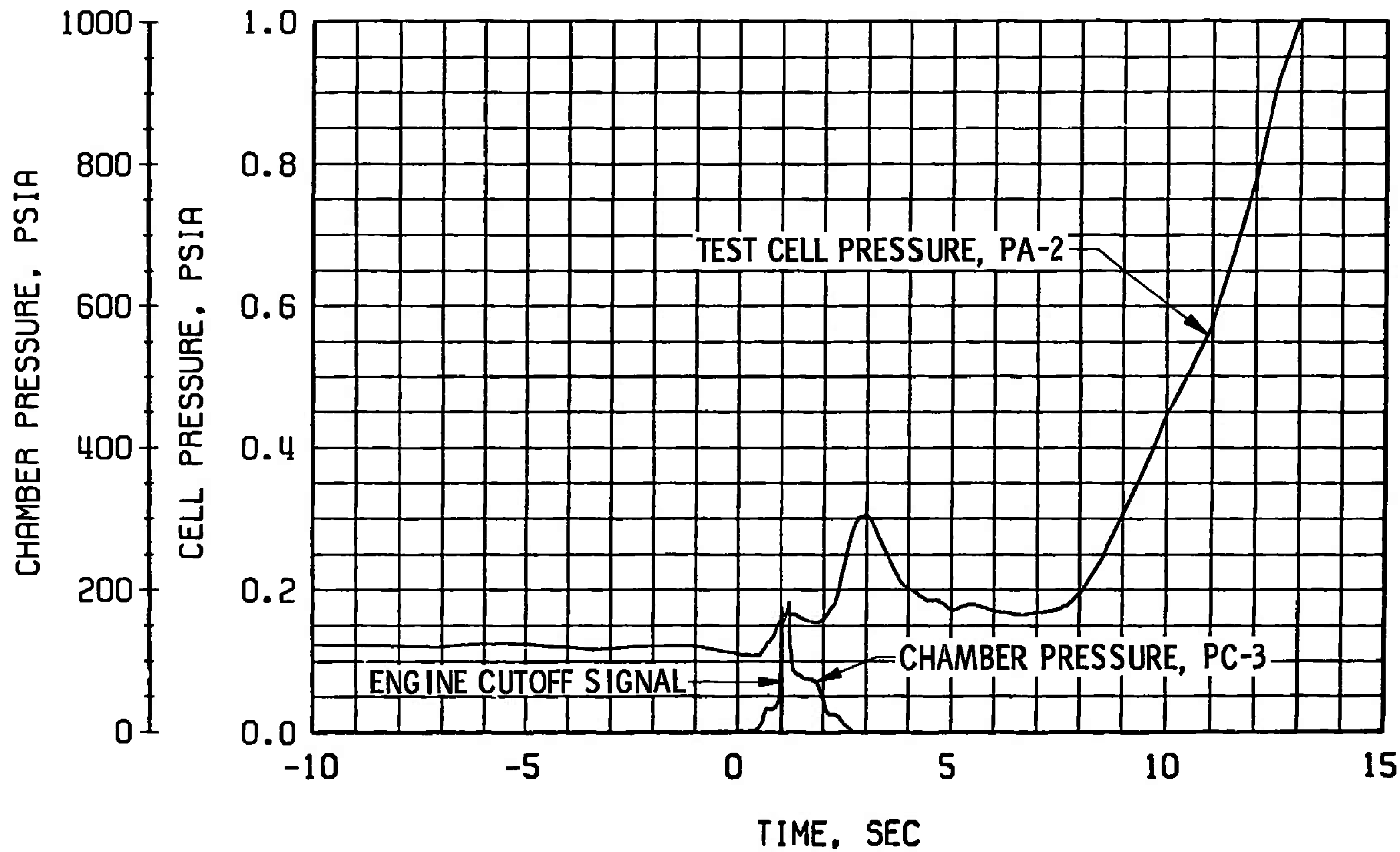
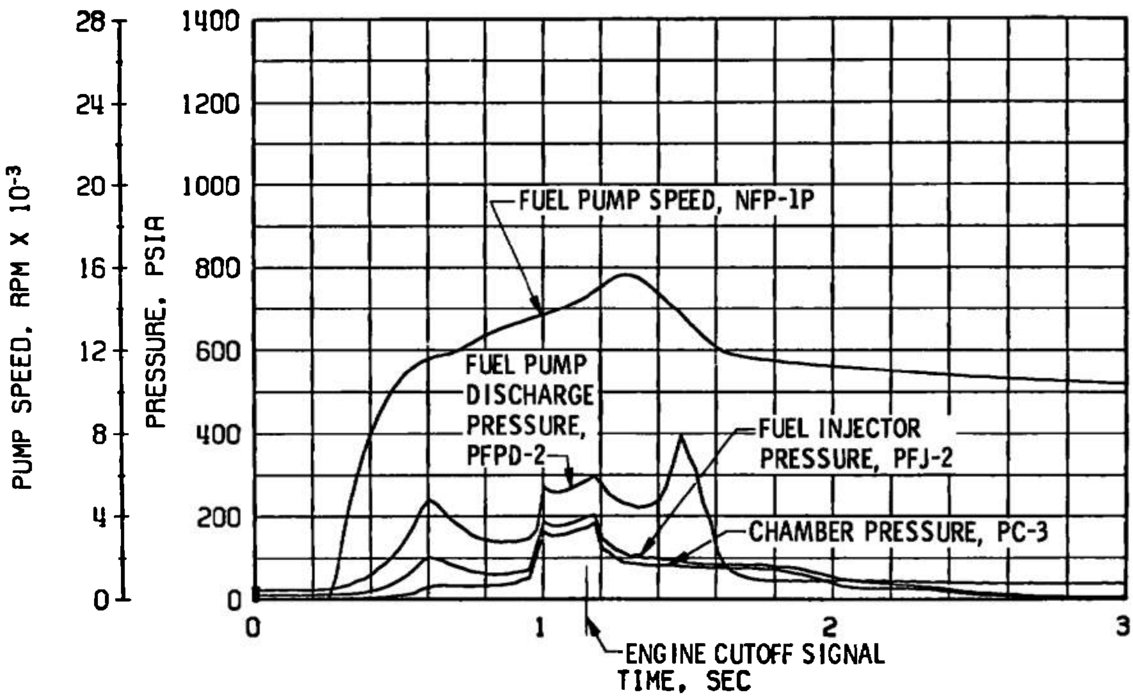
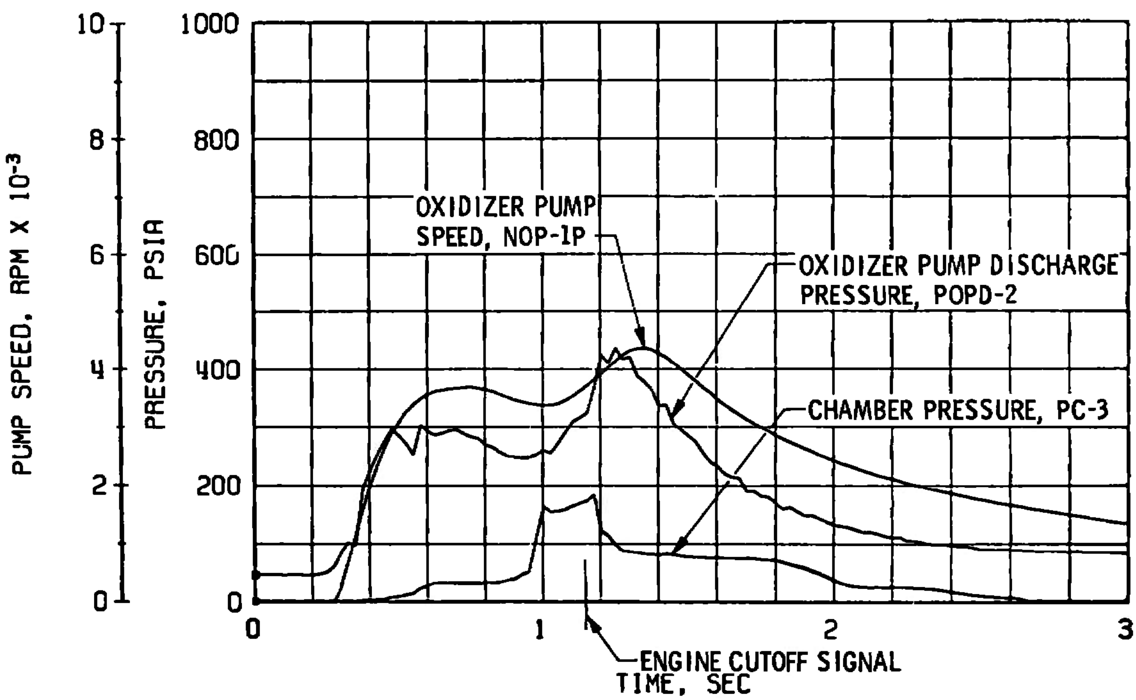


Fig. 106 Engine Ambient and Combustion Chamber Pressures, Firing 32G

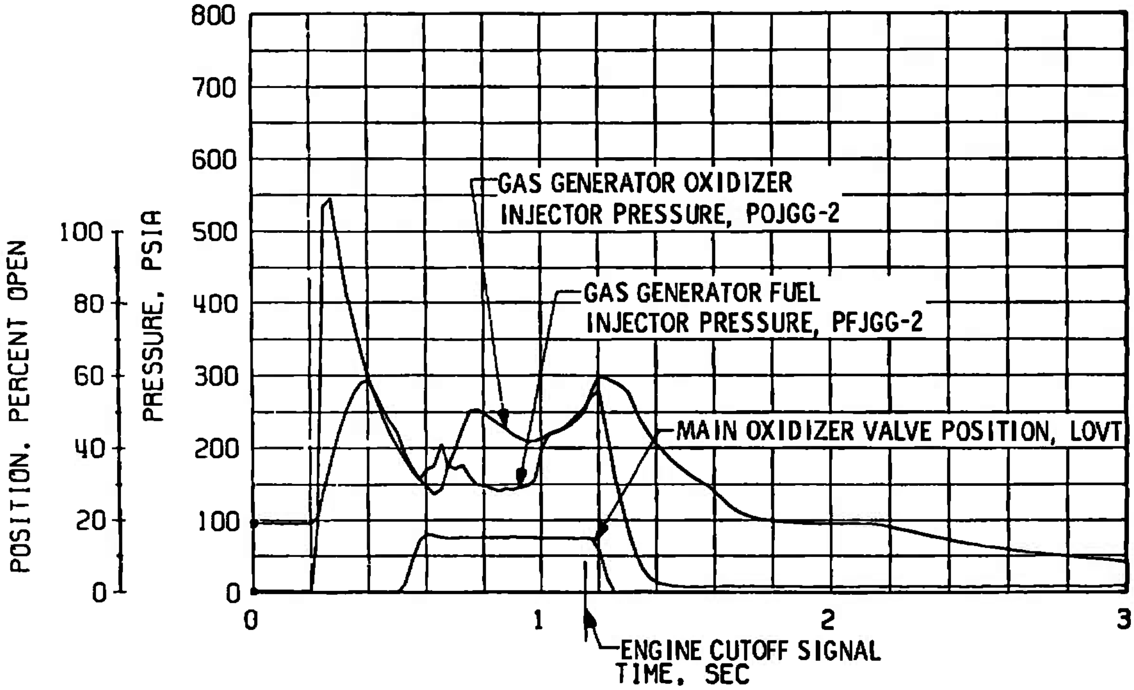


a. Thrust Chamber Fuel System, Start and Shutdown

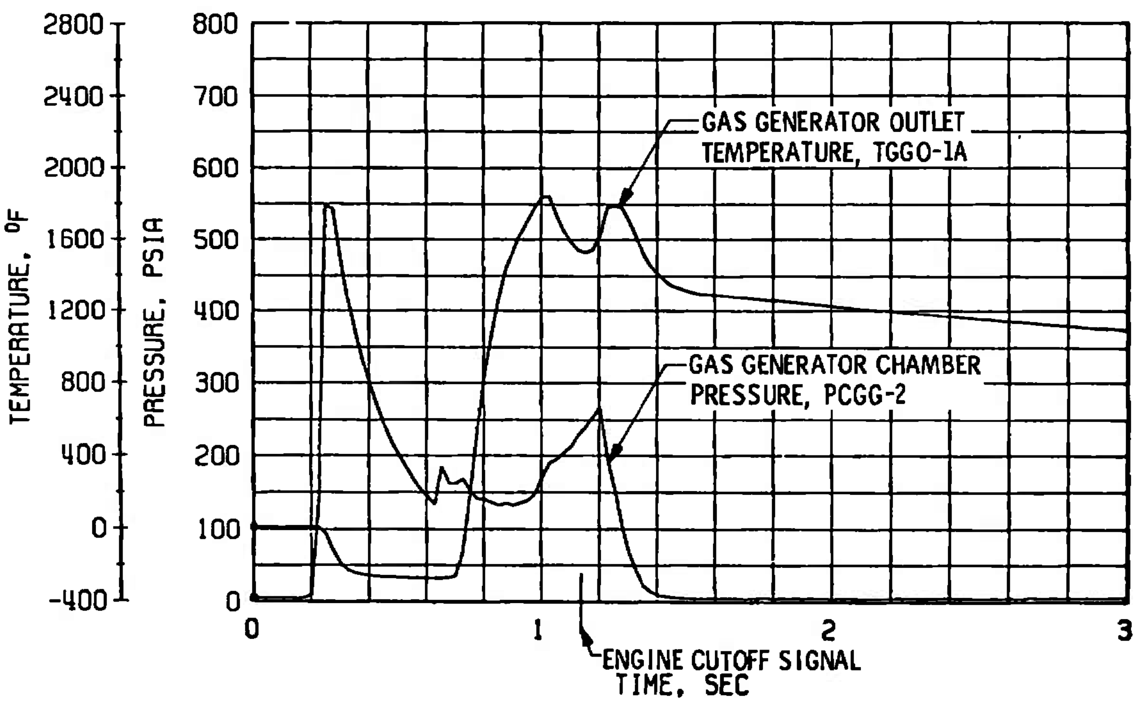


b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 107 Engine Transient Operation, Firing 32G



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 107 Concluded

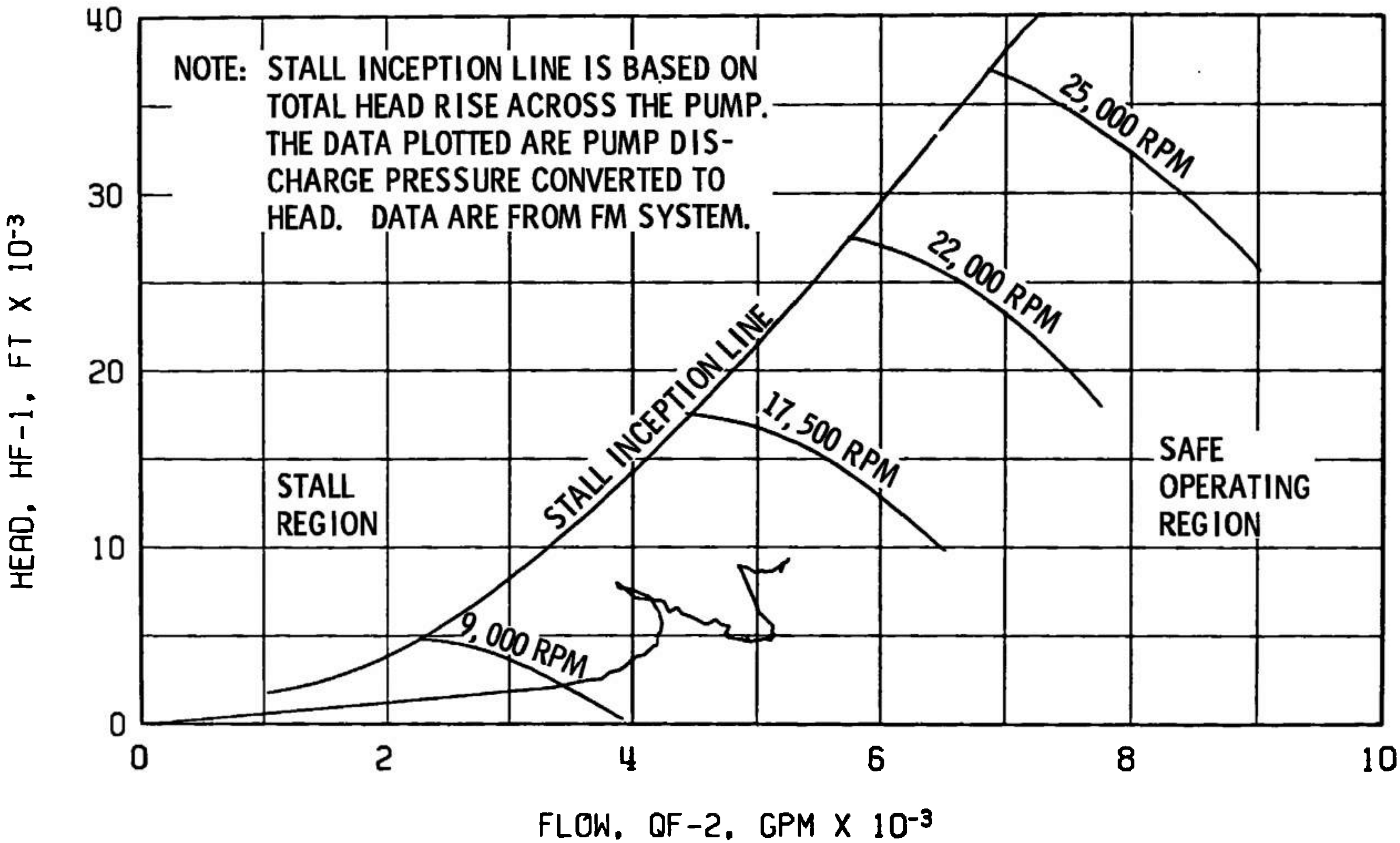
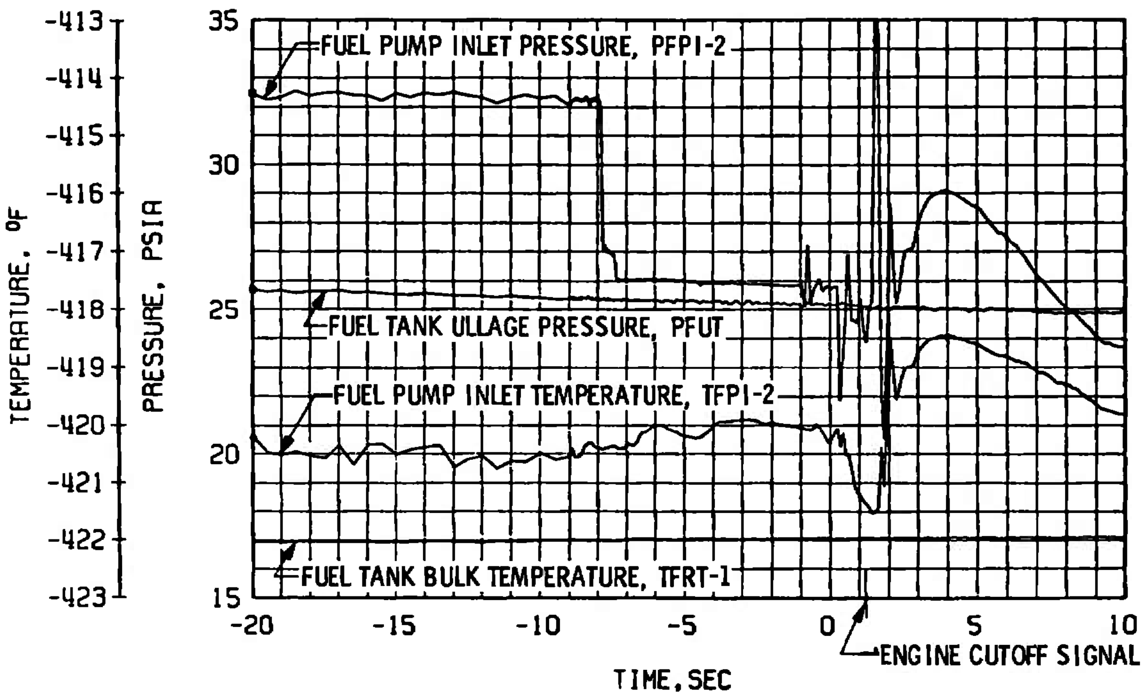
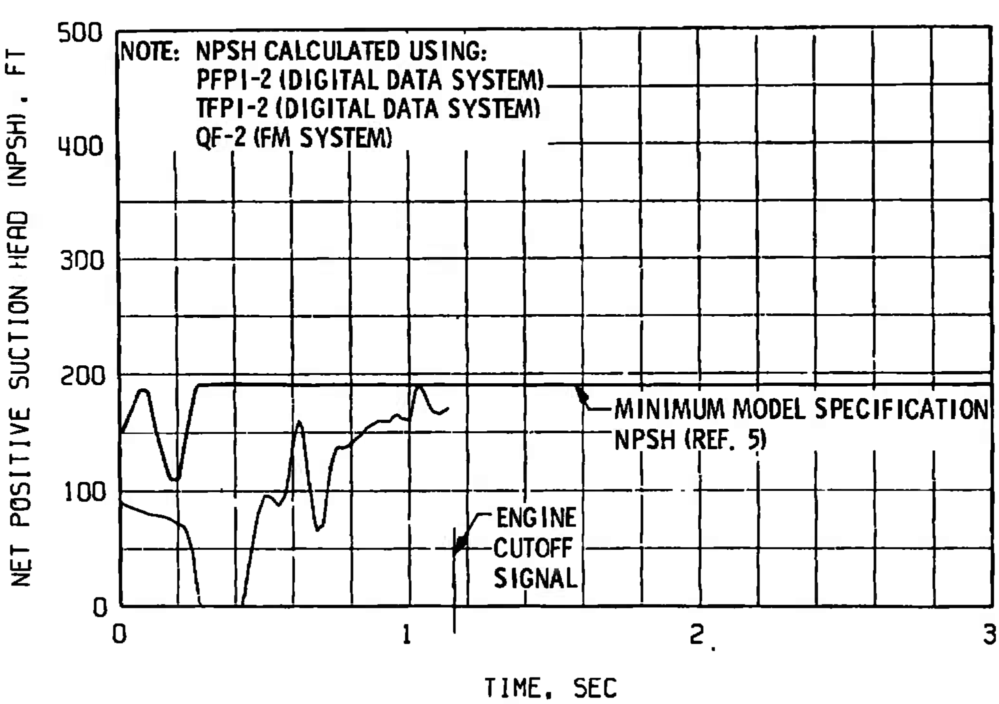


Fig. 108 Fuel Pump Start Transient Performance, Firing 32G

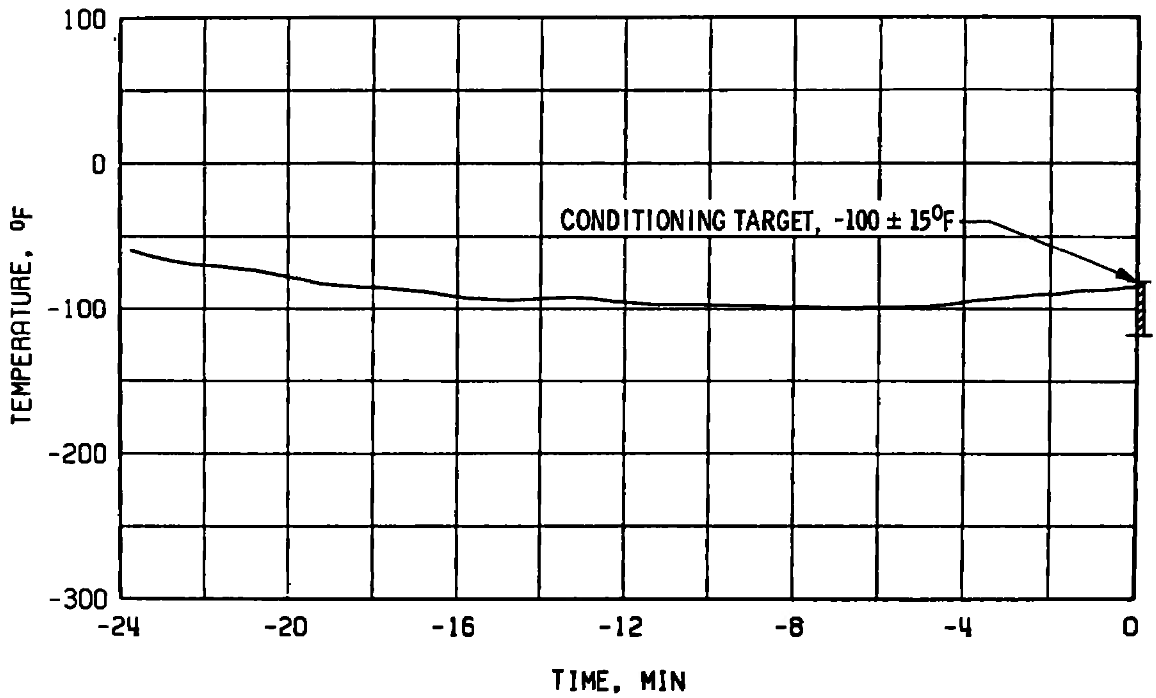


a. Duct Pressure and Temperature Transients

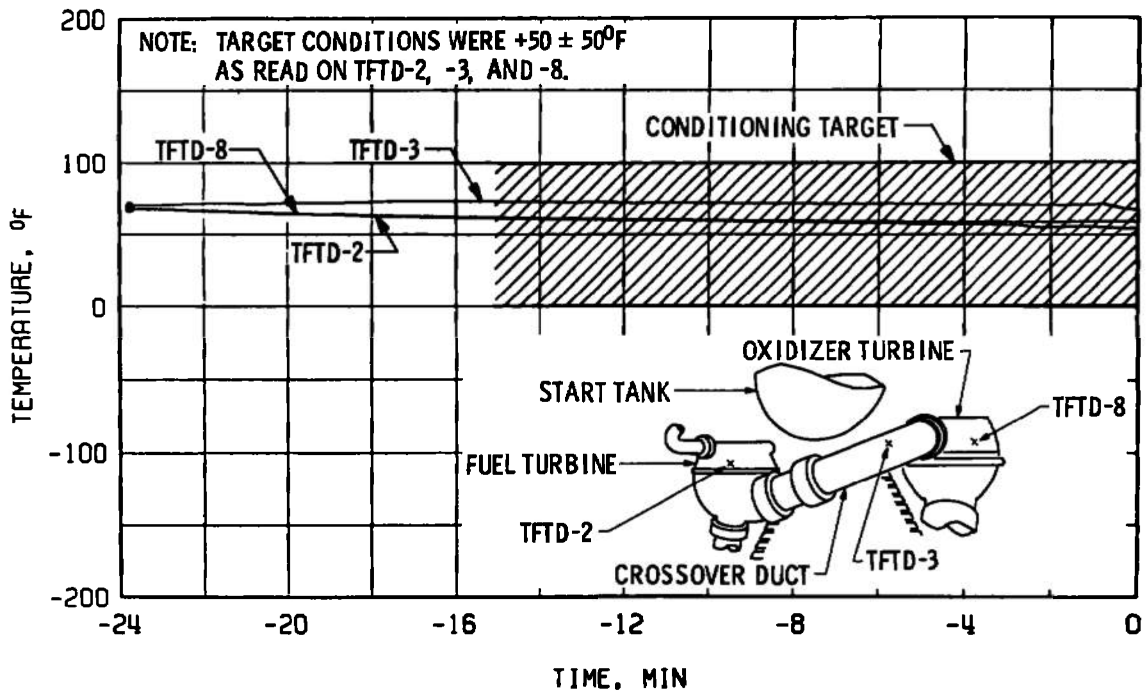


b. Fuel Pump NPSH during Start Transient, Firing 32G

Fig. 109 Fuel Low Pressure Duct Performance, Firing 32G

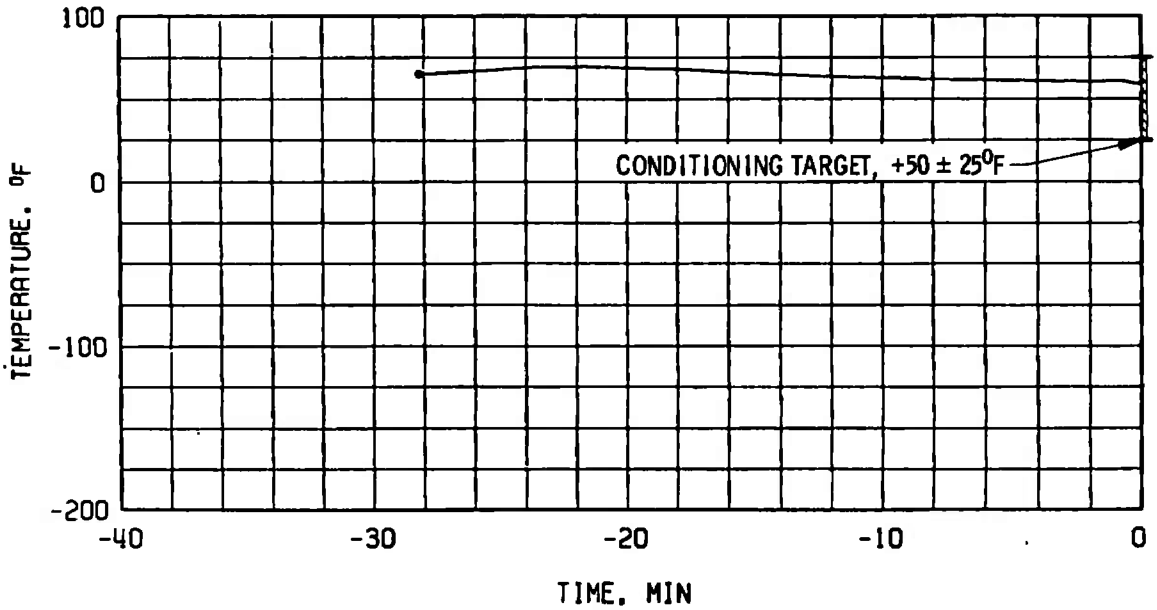


a. Thrust Chamber Throat, TTC-1P

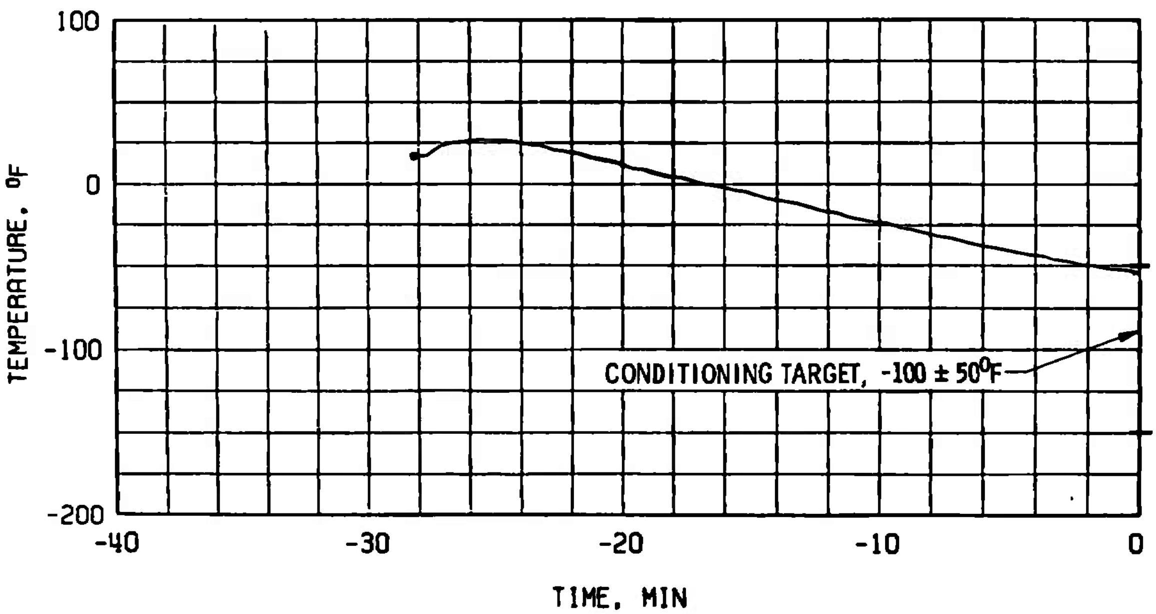


b. Crossover Duct, TFTD

Fig. 110 Thermal Conditioning History of Engine Components, Firing 33A



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 110 Concluded

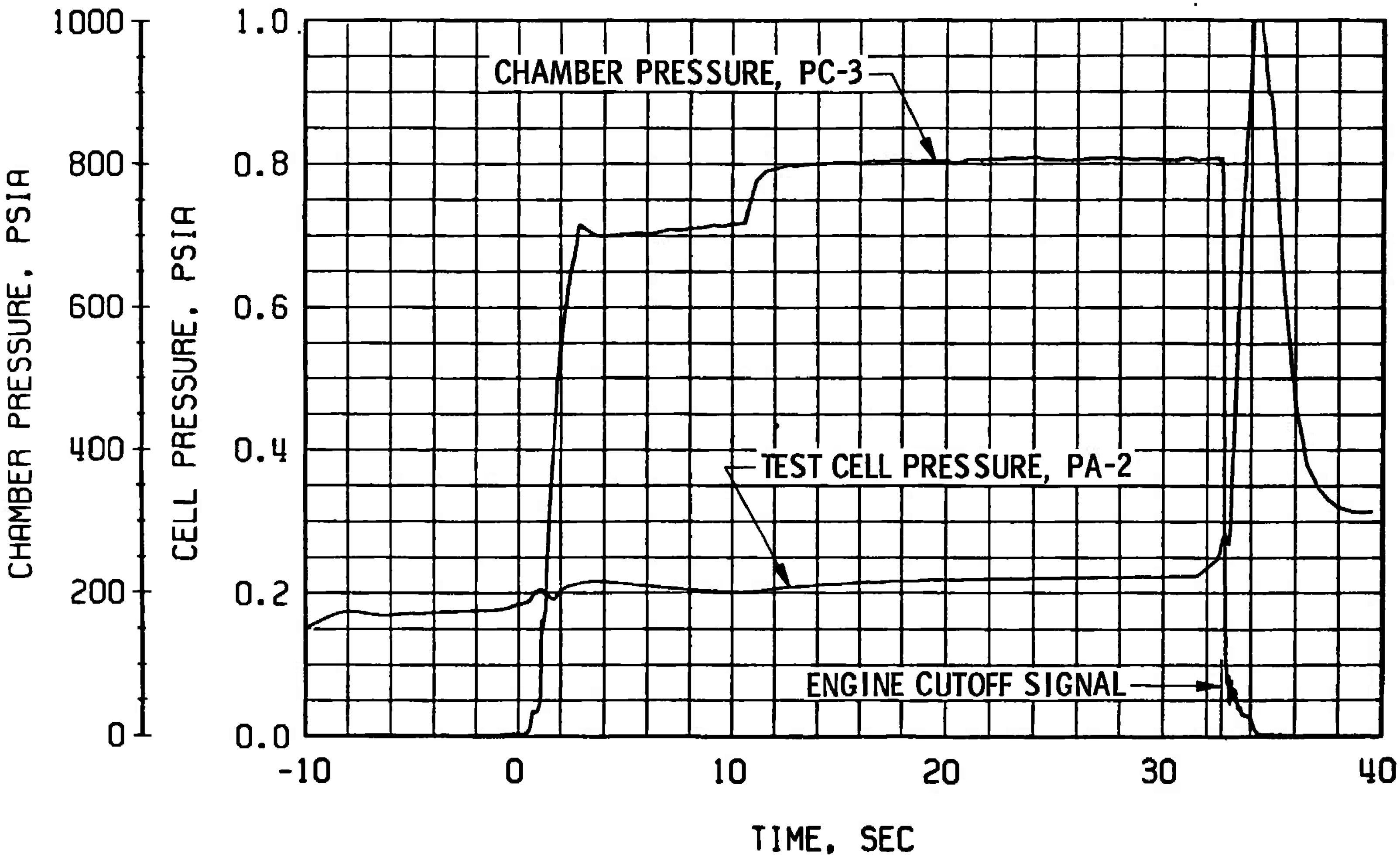
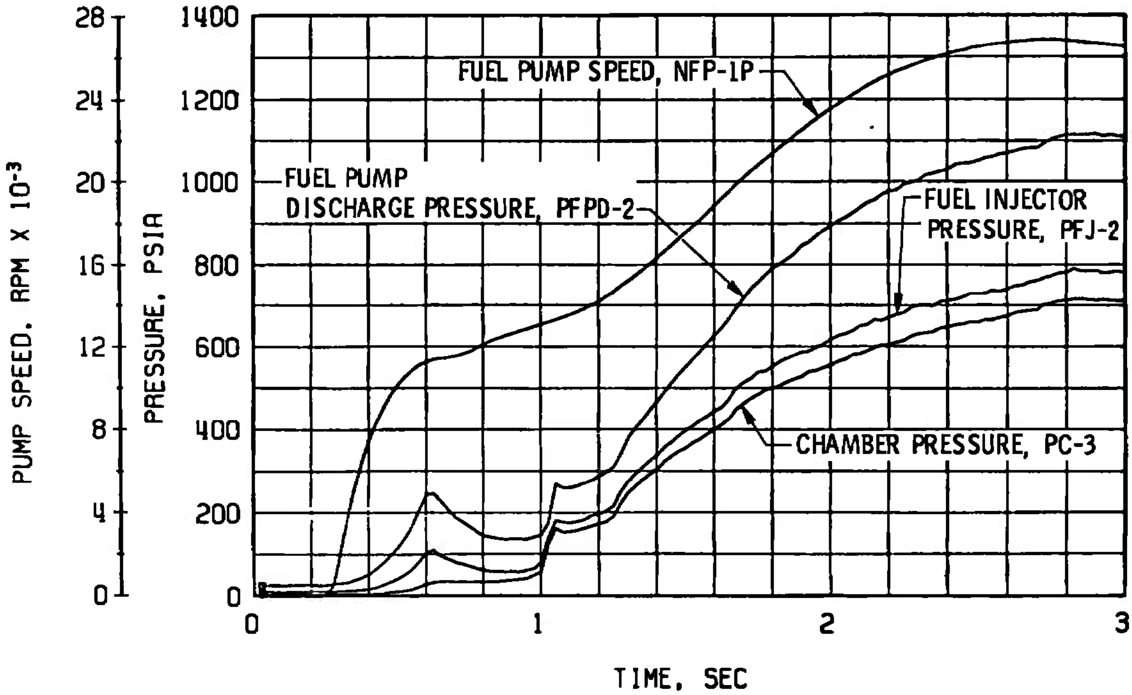
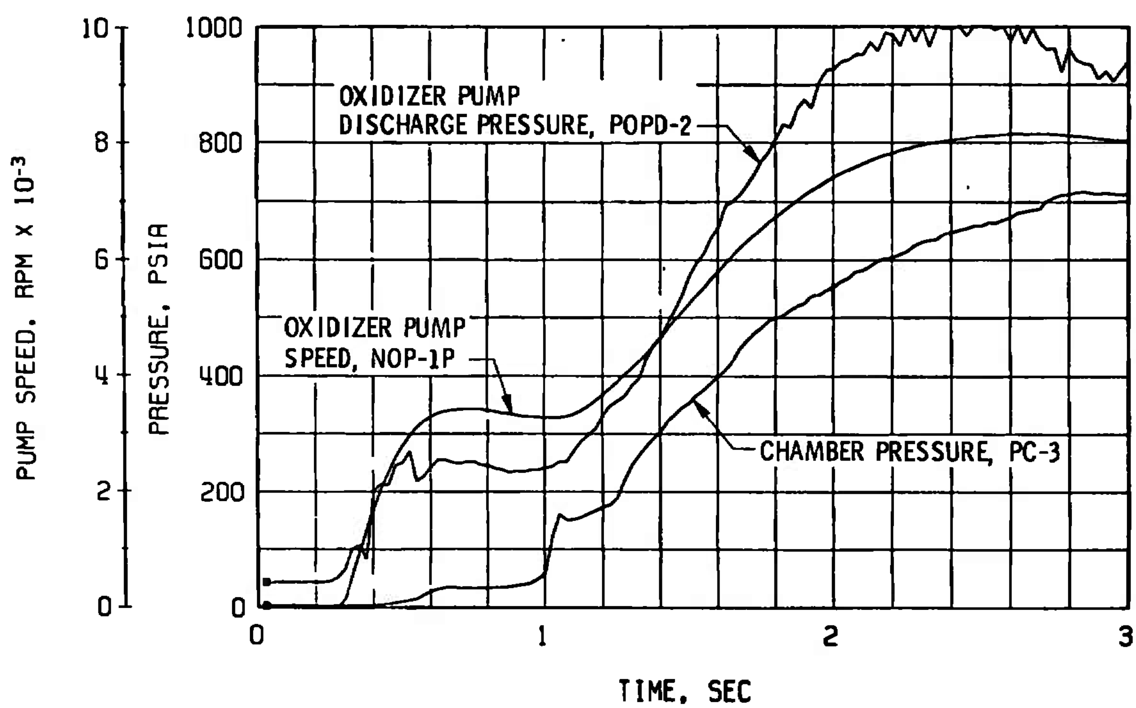


Fig. 111 Engine Ambient and Combustion Chamber Pressures, Firing 33A

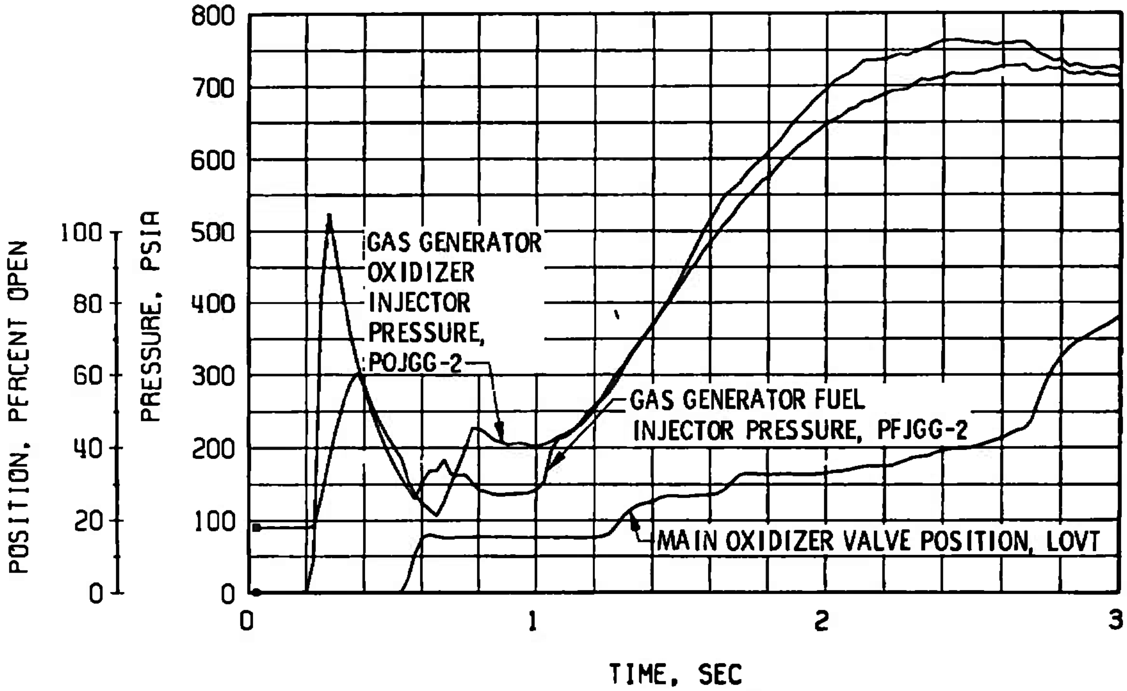


a. Thrust Chamber Fuel System, Start

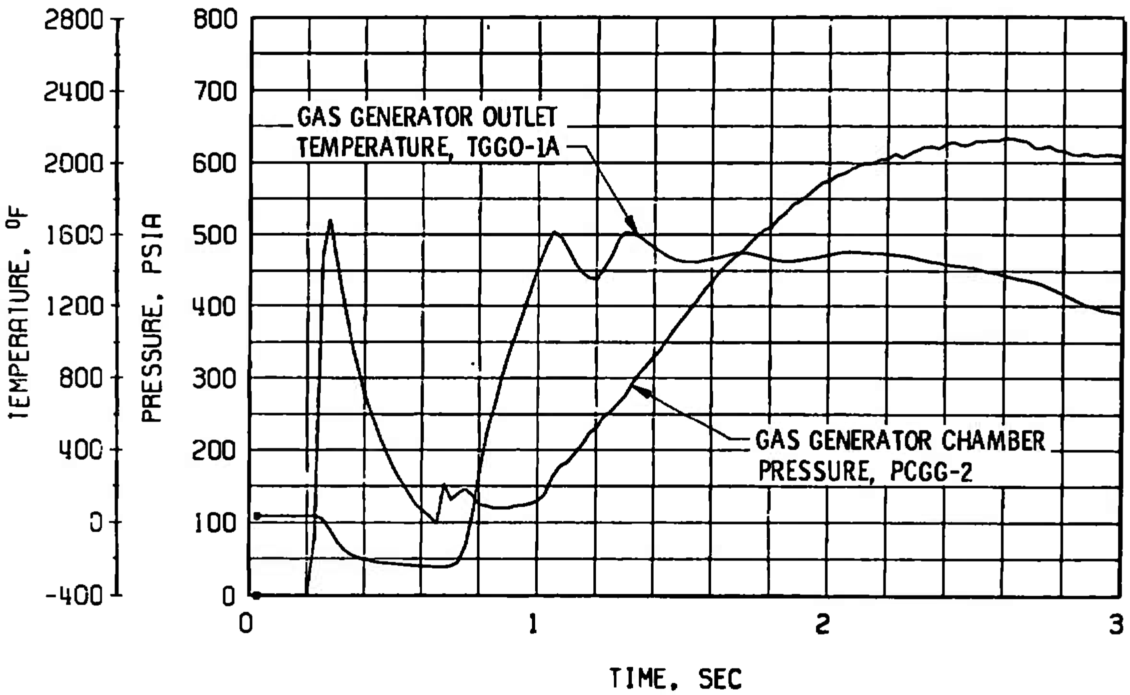


b. Thrust Chamber Oxidizer System, Start

Fig. 112 Engine Transient Operation, Firing 33A

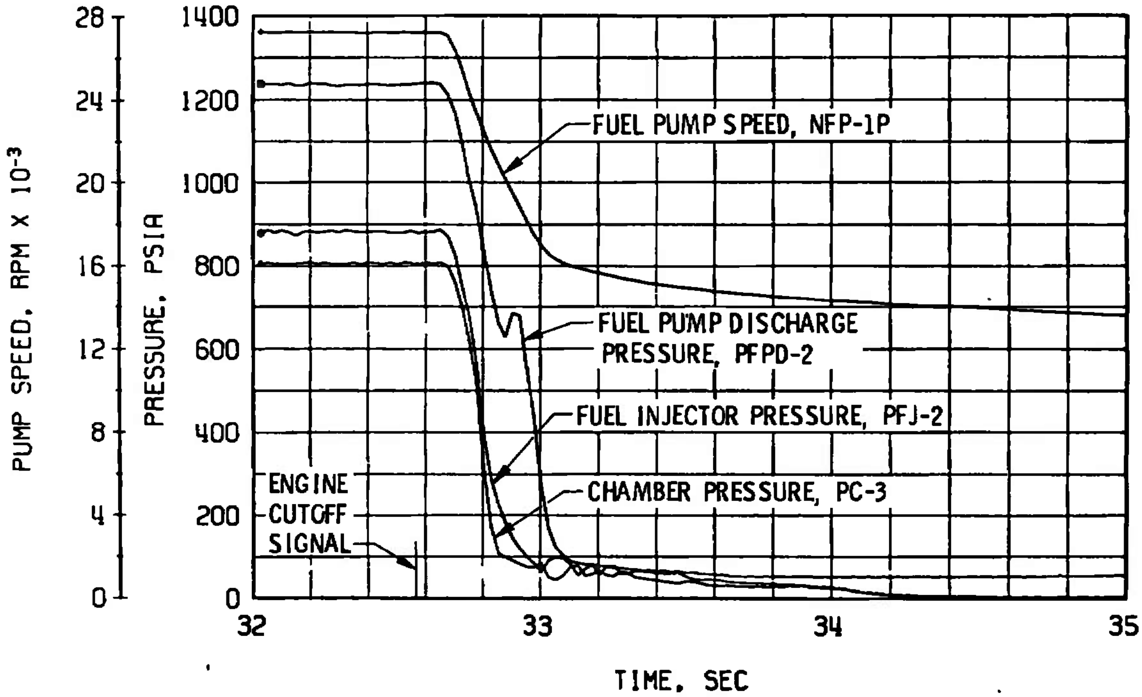


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

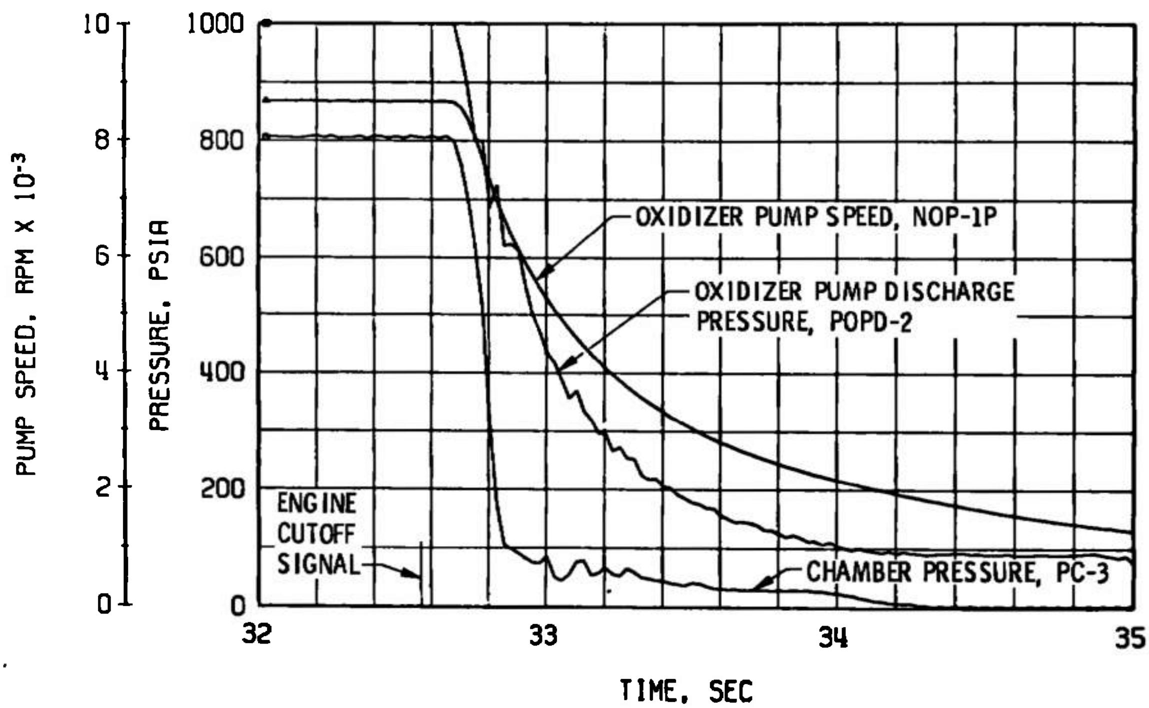


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 112 Continued

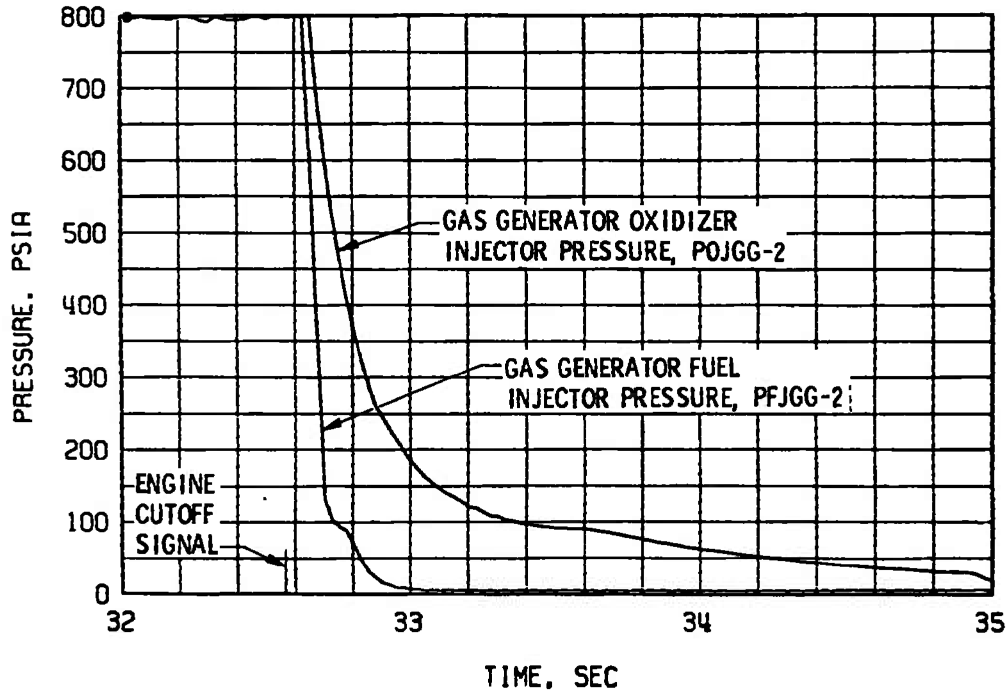


e. Thrust Chamber Fuel System, Shutdown

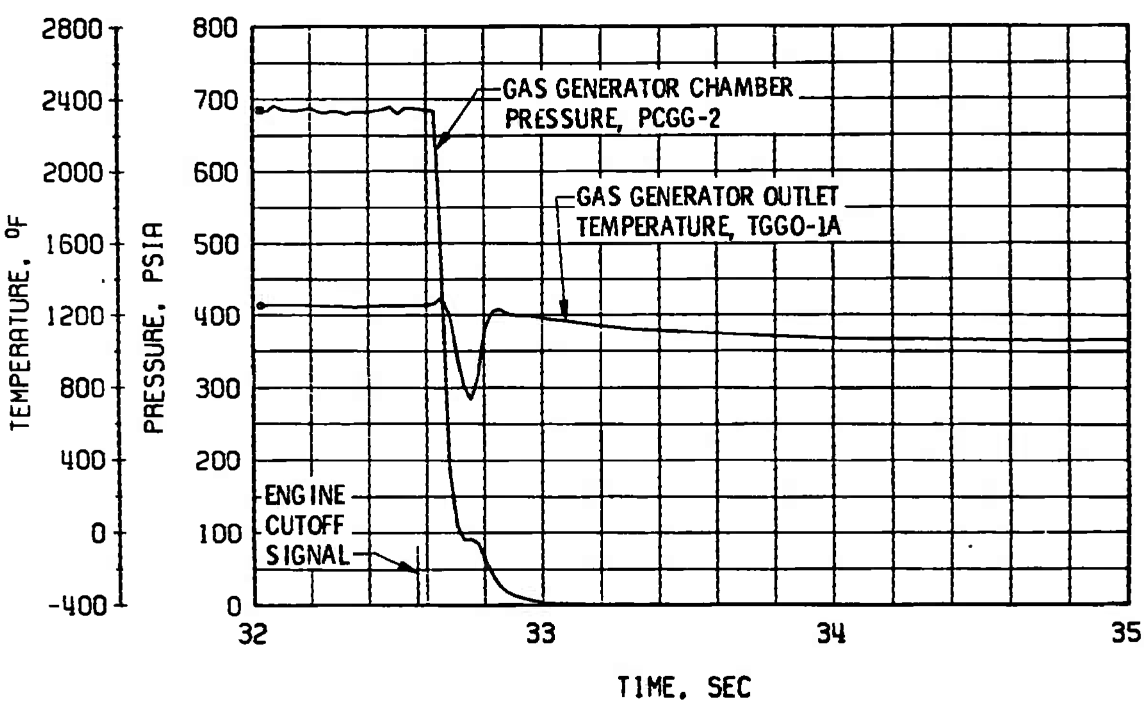


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 112 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 112 Concluded

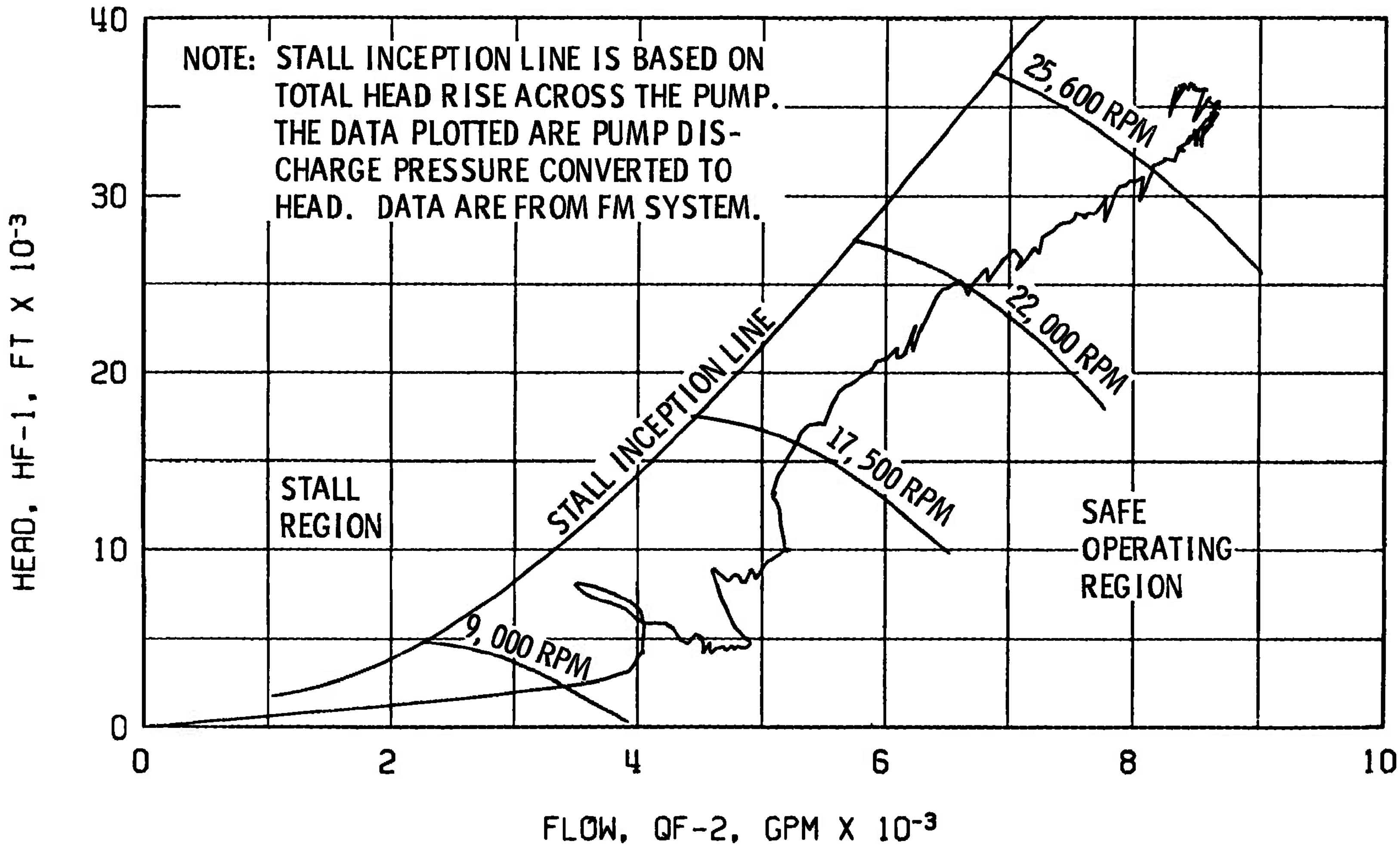
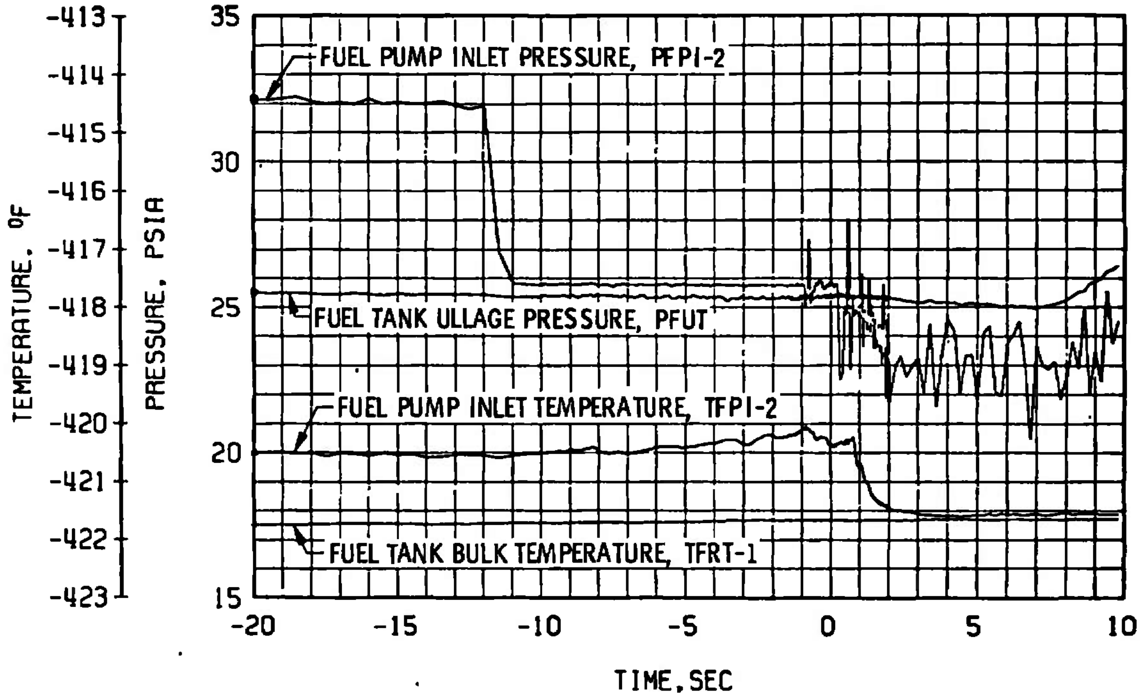
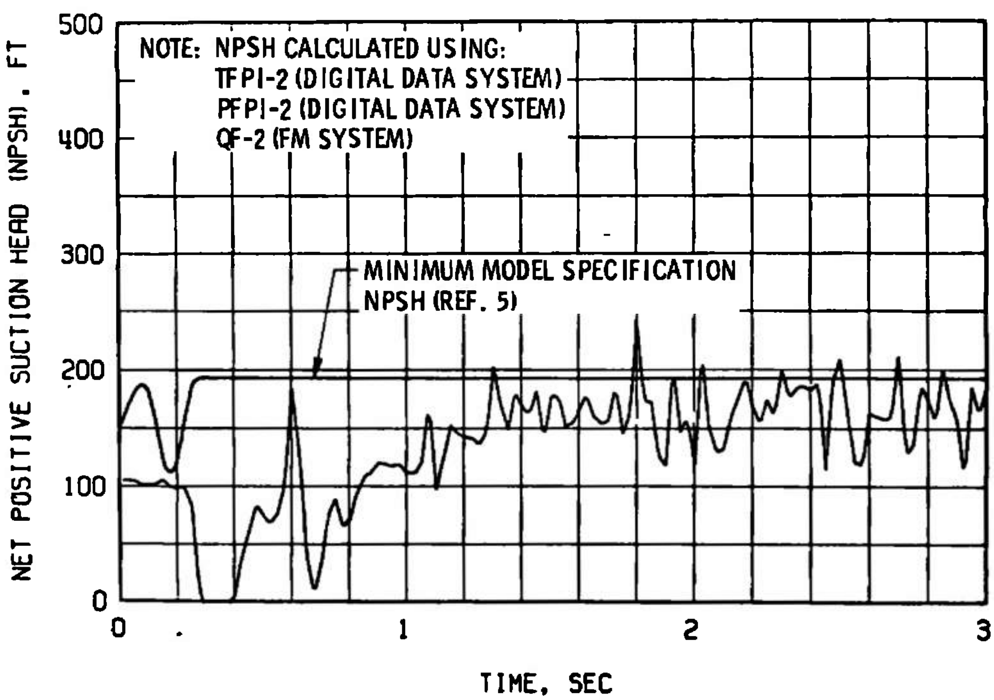


Fig. 113 Fuel Pump Start Transient Performance, Firing 33A

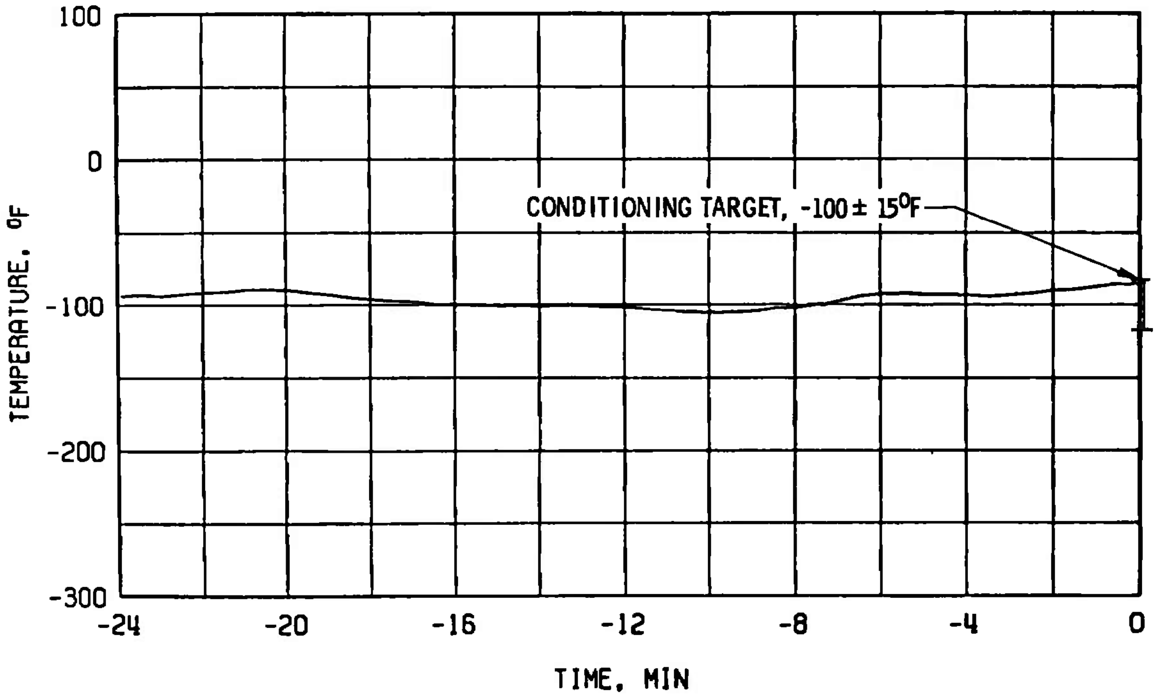


a. Duct Pressure and Temperature Transients

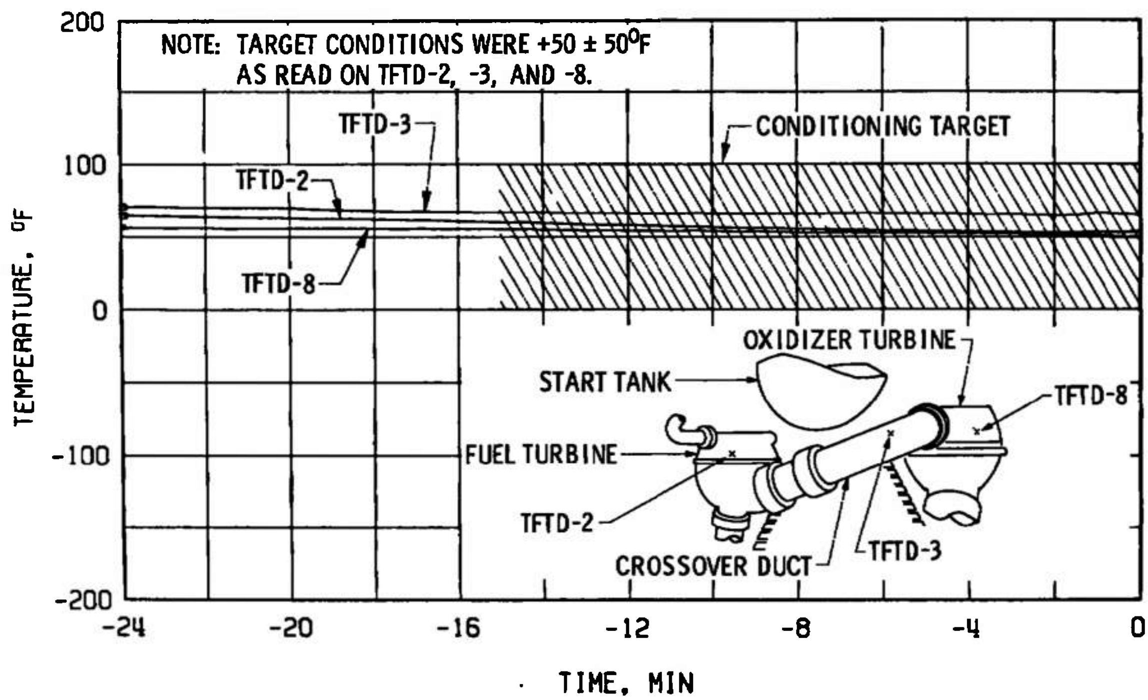


b. Fuel Pump NPSH during Start Transient, Firing 33A

Fig. 114 Fuel Low Pressure Duct Performance, Firing 33A

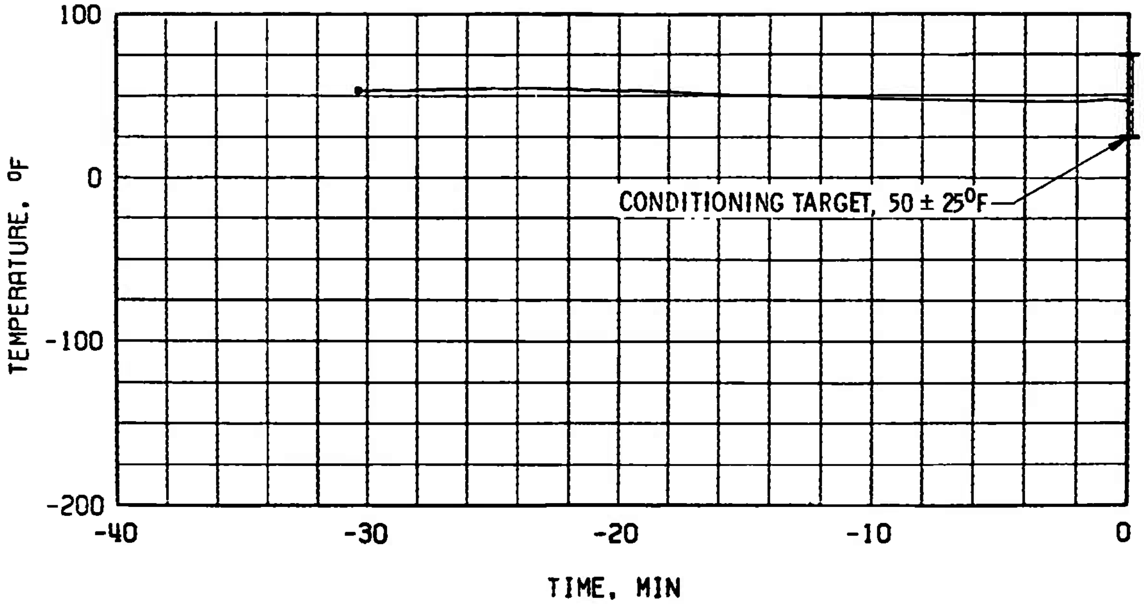


a. Thrust Chamber Throat, TTC-1P

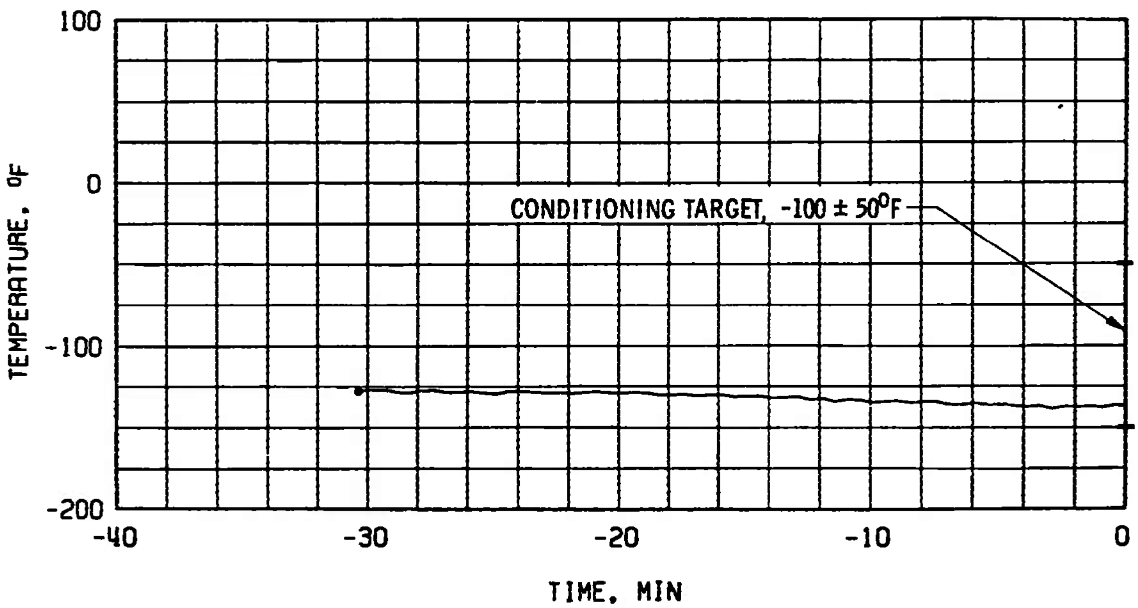


b. Crossover Duct, TFTD

Fig. 115 Thermal Conditioning History of Engine Components, Firing 33B



c. Start Tank Discharge Valve, TSTDVOG



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 115 Concluded

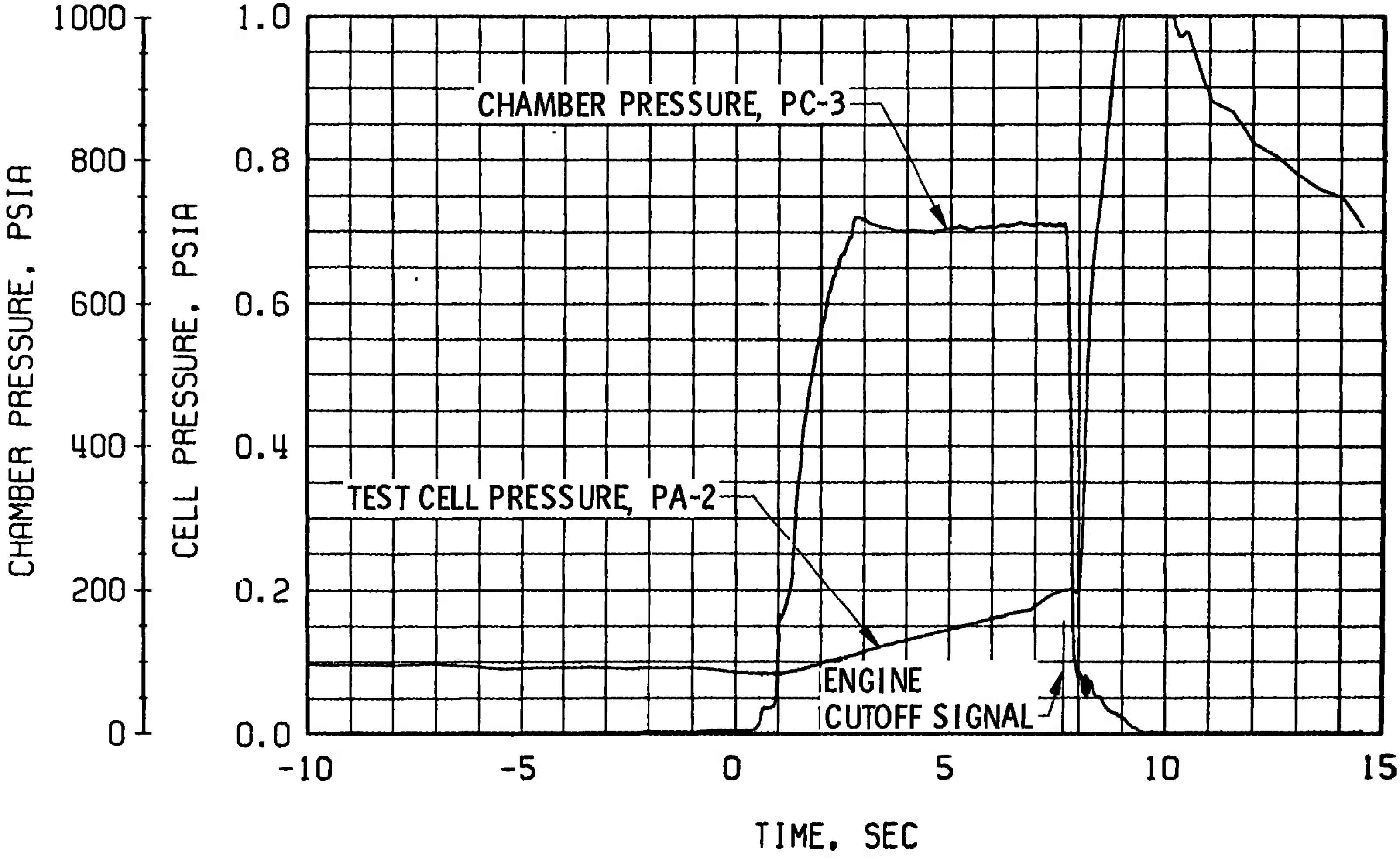
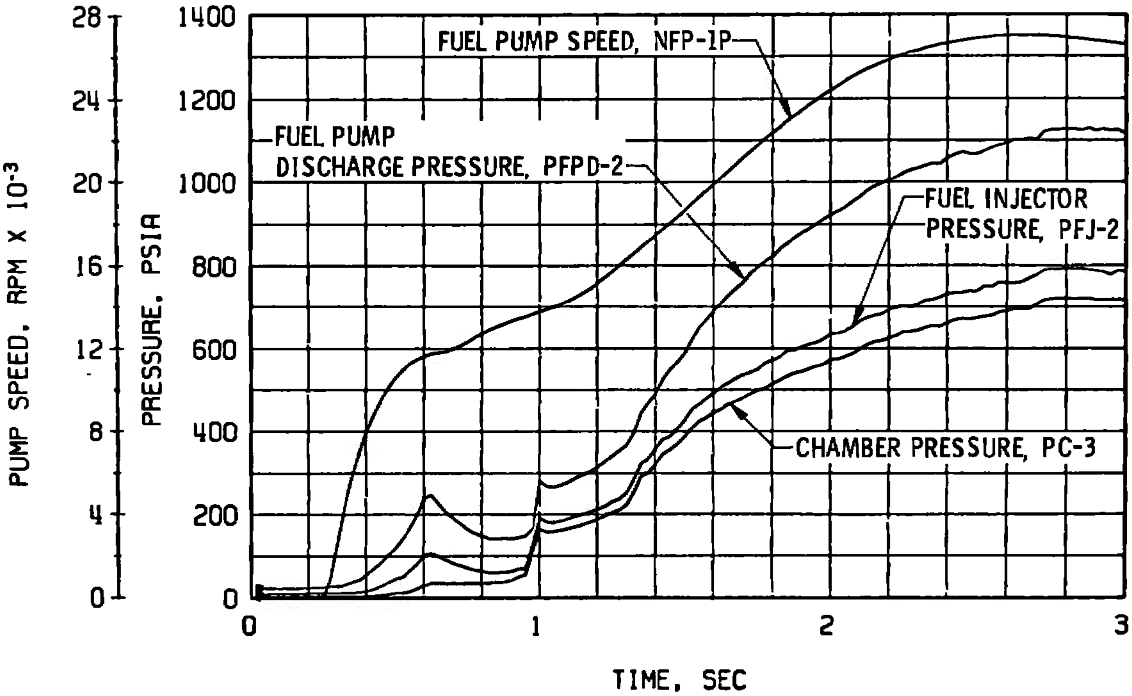
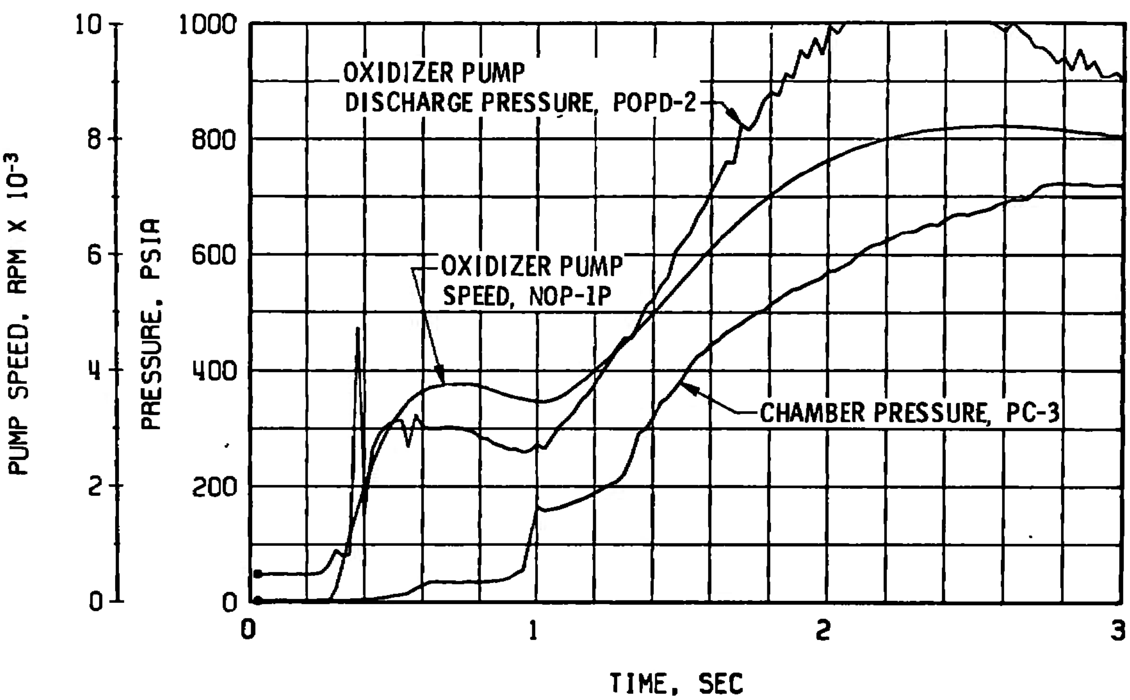


Fig. 116 Engine Ambient and Combustion Chamber Pressures, Firing 33B

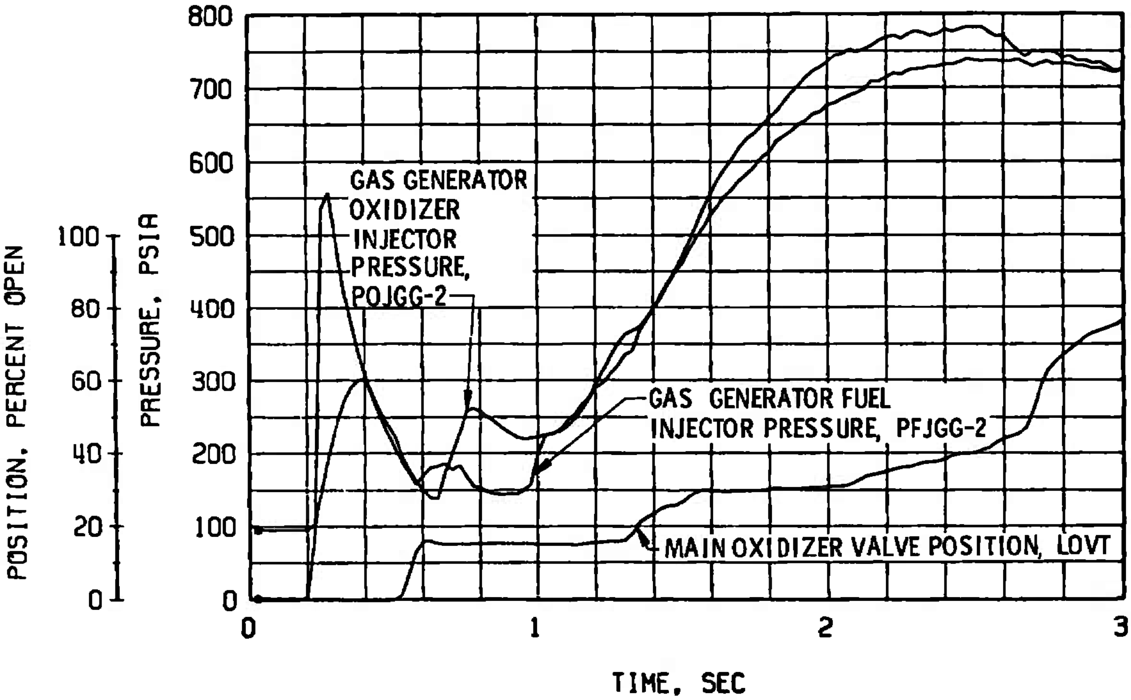


a. Thrust Chamber Fuel System, Start

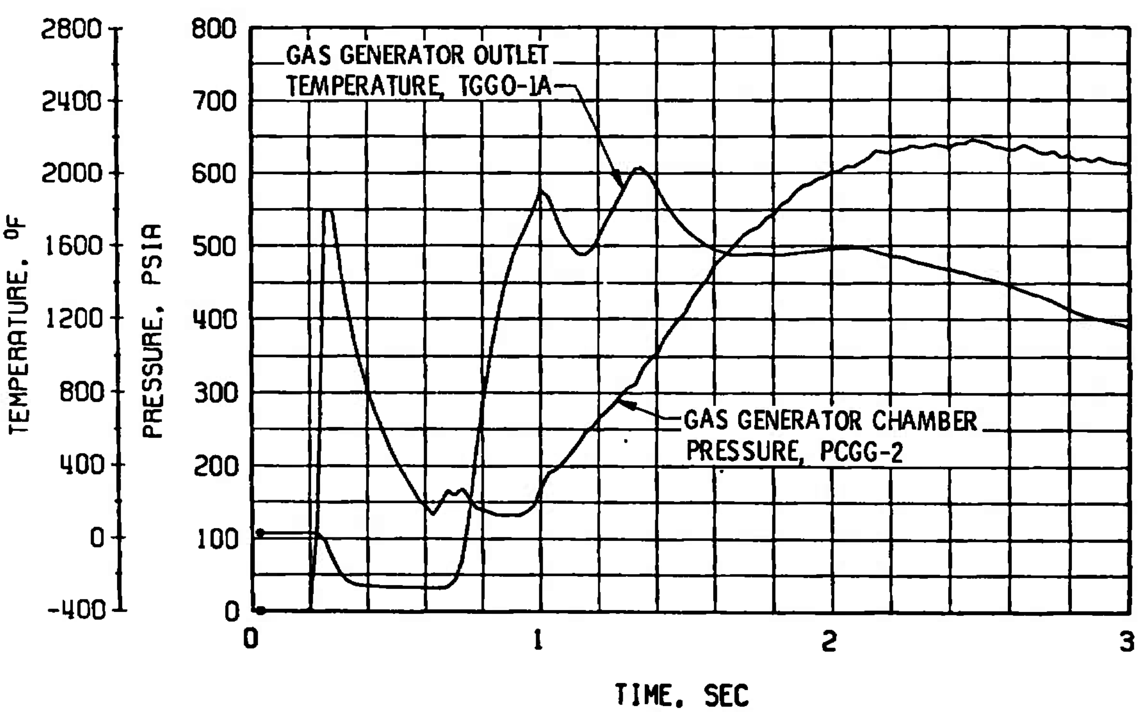


b. Thrust Chamber Oxidizer System, Start

Fig. 117 Engine Transient Operation, Firing 33B

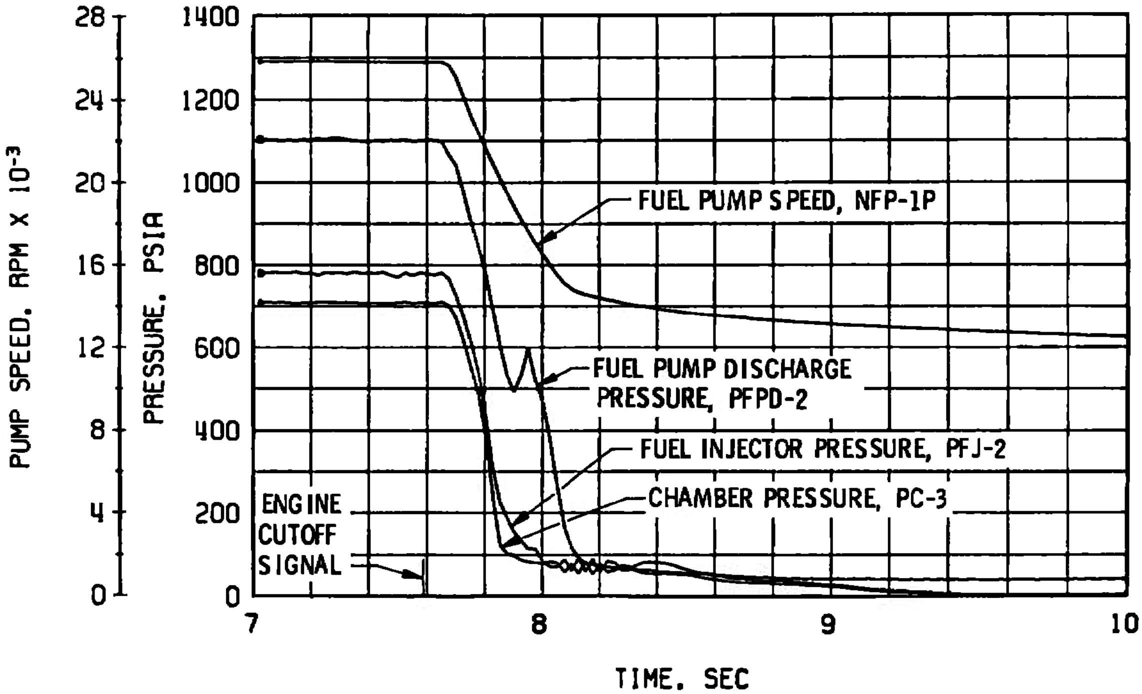


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

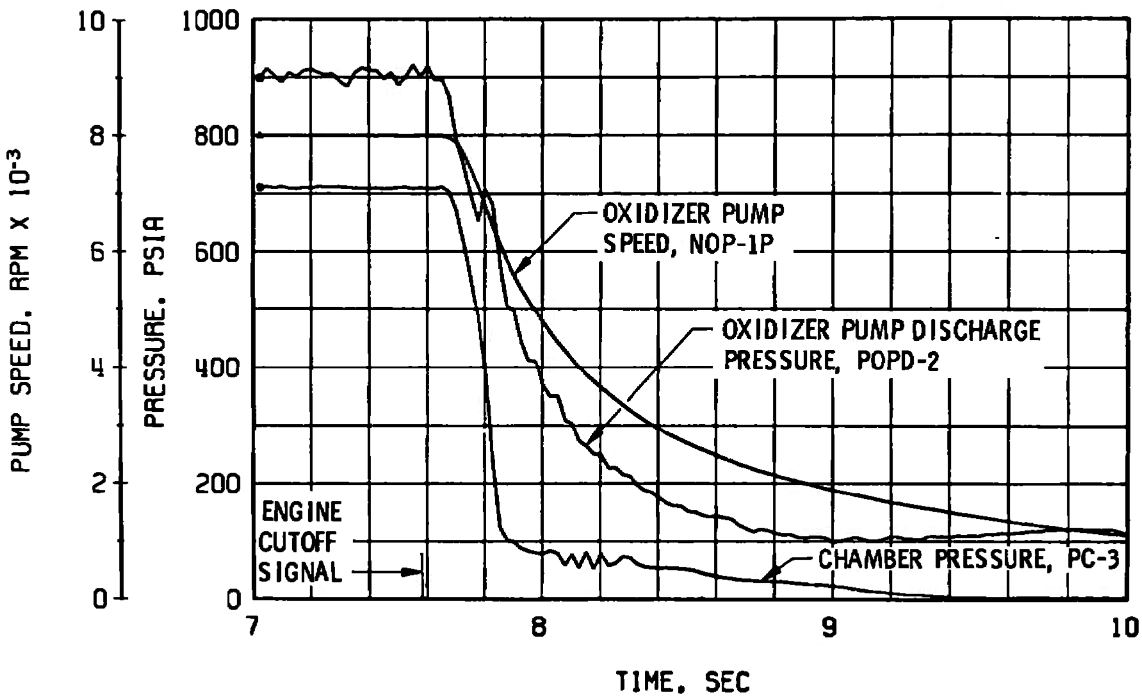


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 117 Continued

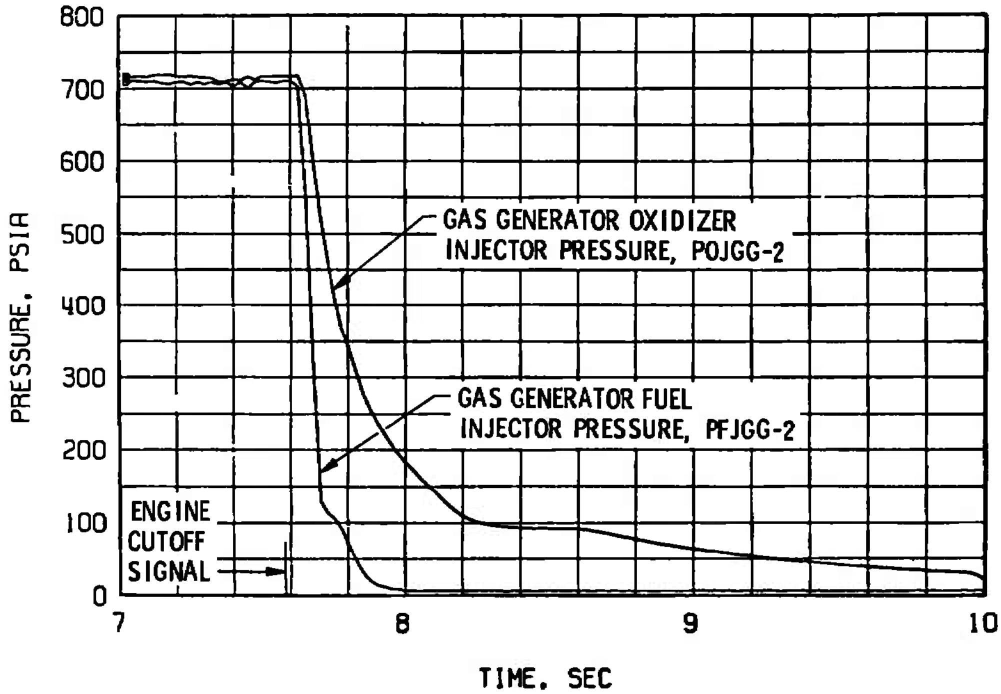


e. Thrust Chamber Fuel System, Shutdown

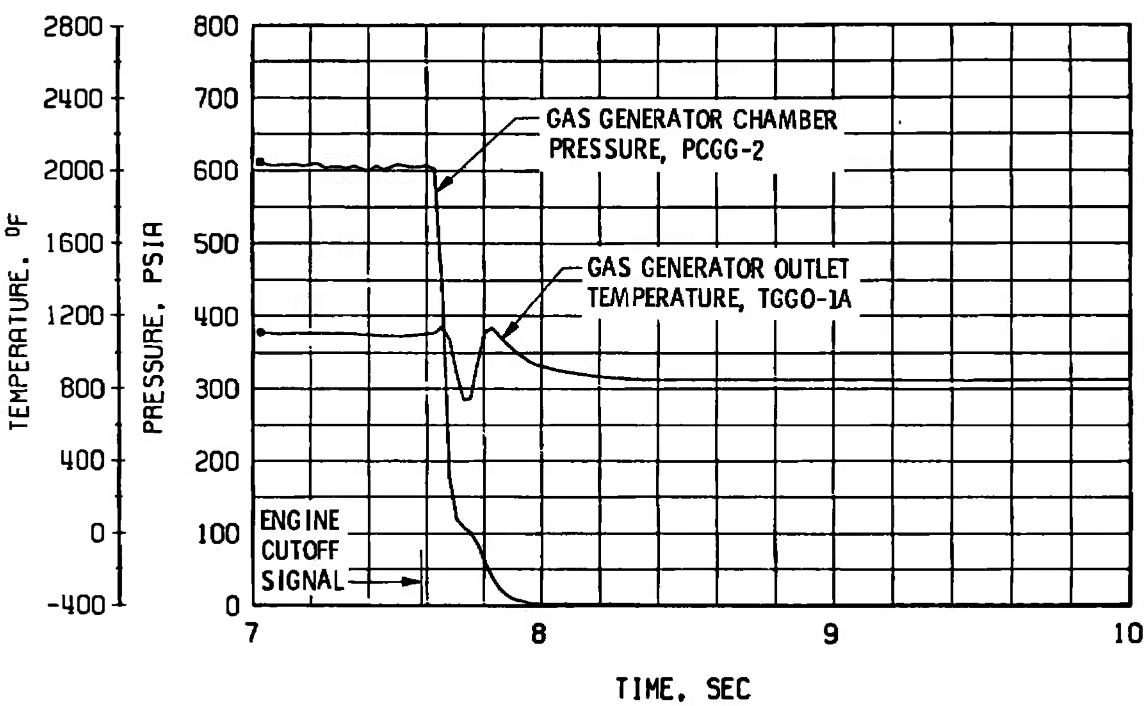


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 117 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 117 Concluded

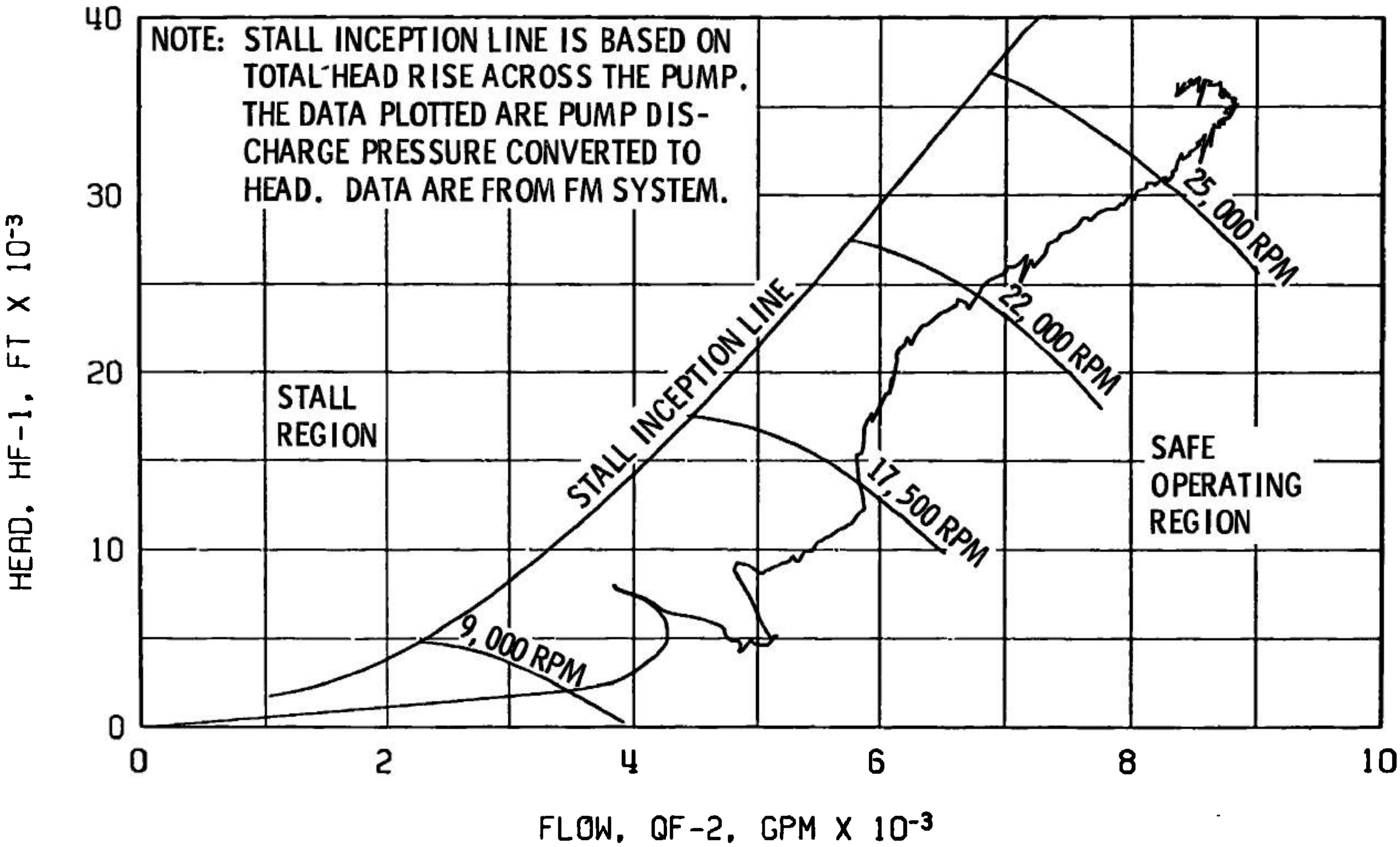
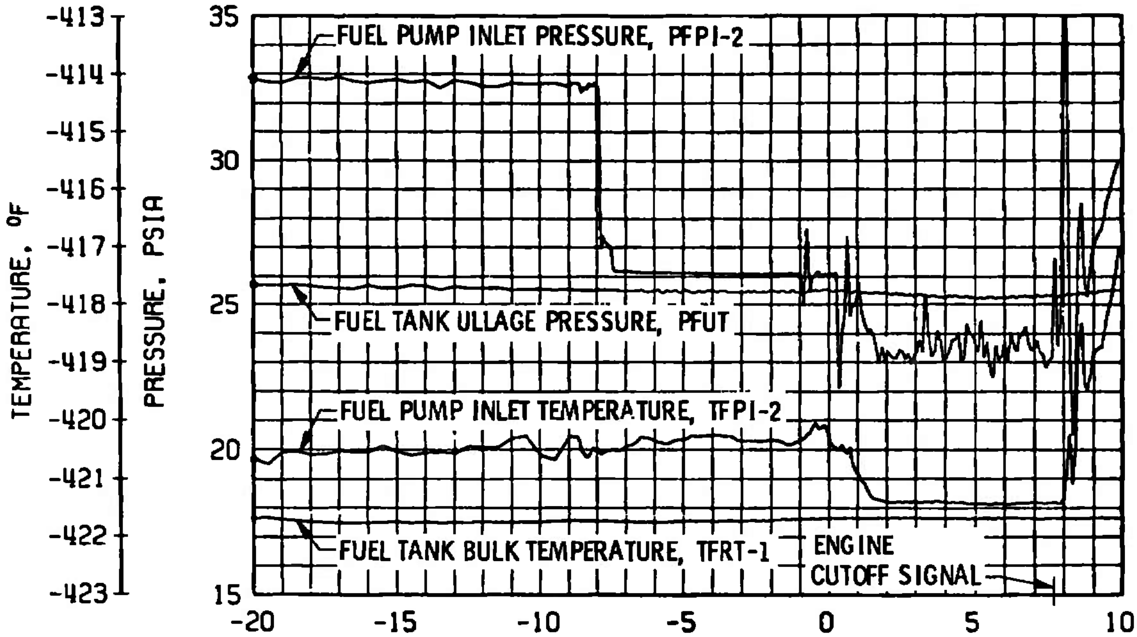
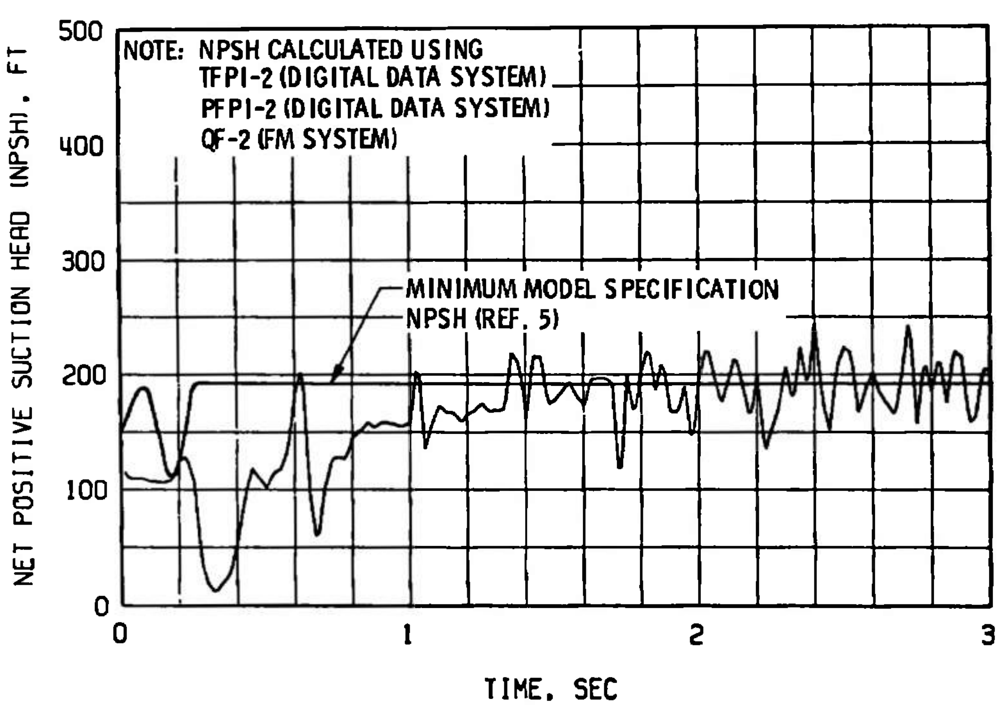


Fig. 118 Fuel Pump Start Transient Performance, Firing 33B

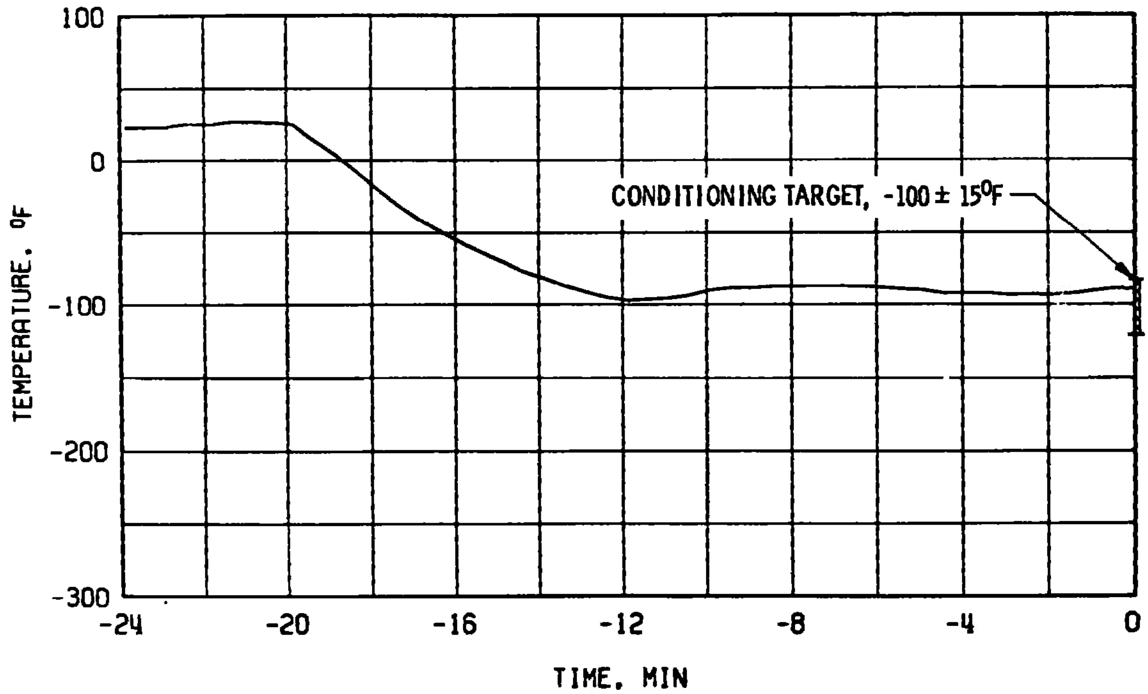


a. Duct Pressure and Temperature Transients

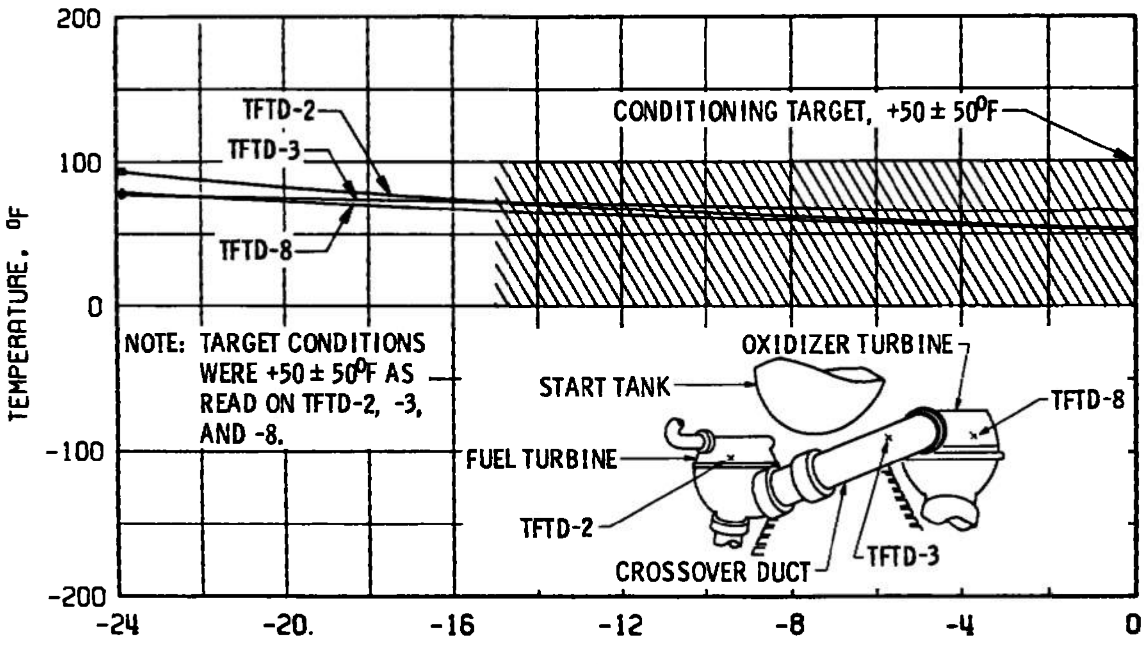


b. Fuel Pump NPSH during Start Transients

Fig. 119 Fuel Low Pressure Duct Performance, Firing 33B

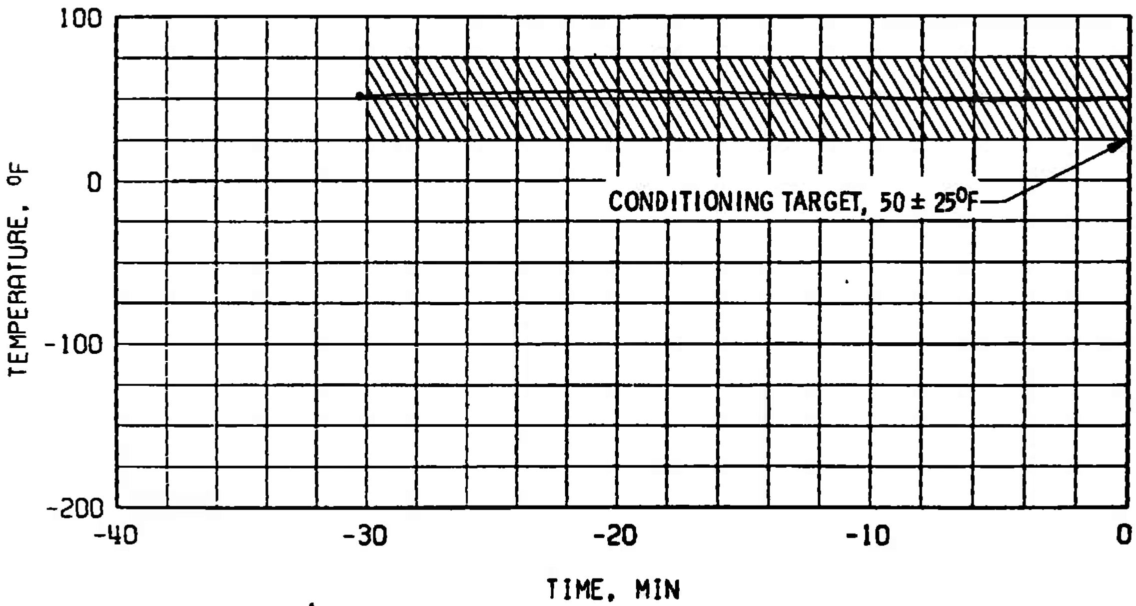


a. Thrust Chamber Throat, TTC-1P

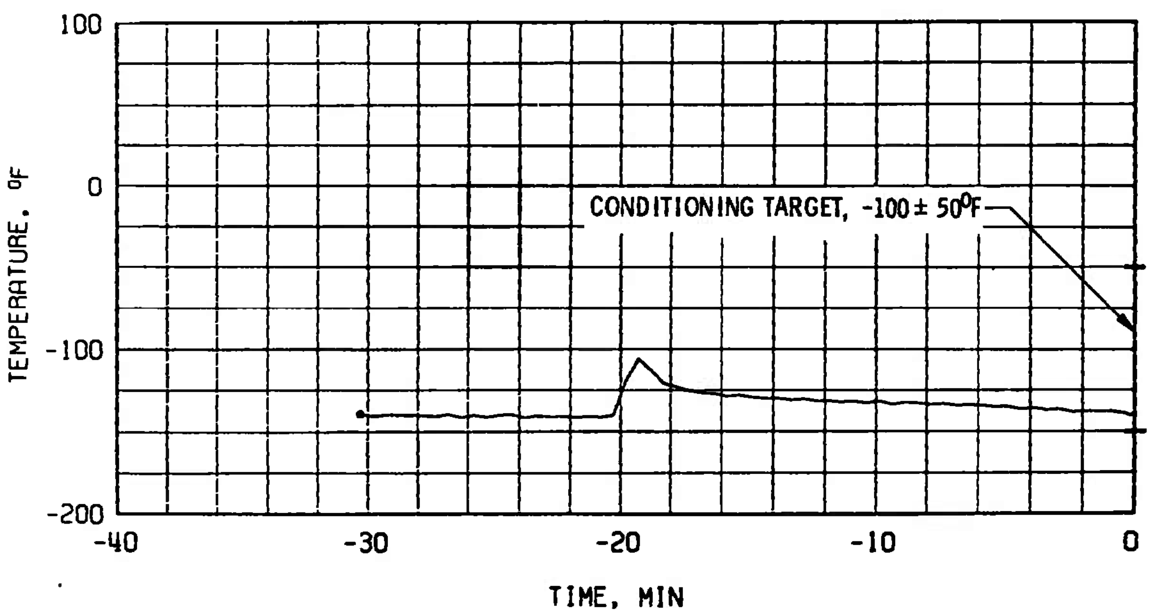


b. Crossover Duct, TFTD

Fig. 120 Thermal Conditioning History of Engine Components, Firing 33C



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 120 Concluded

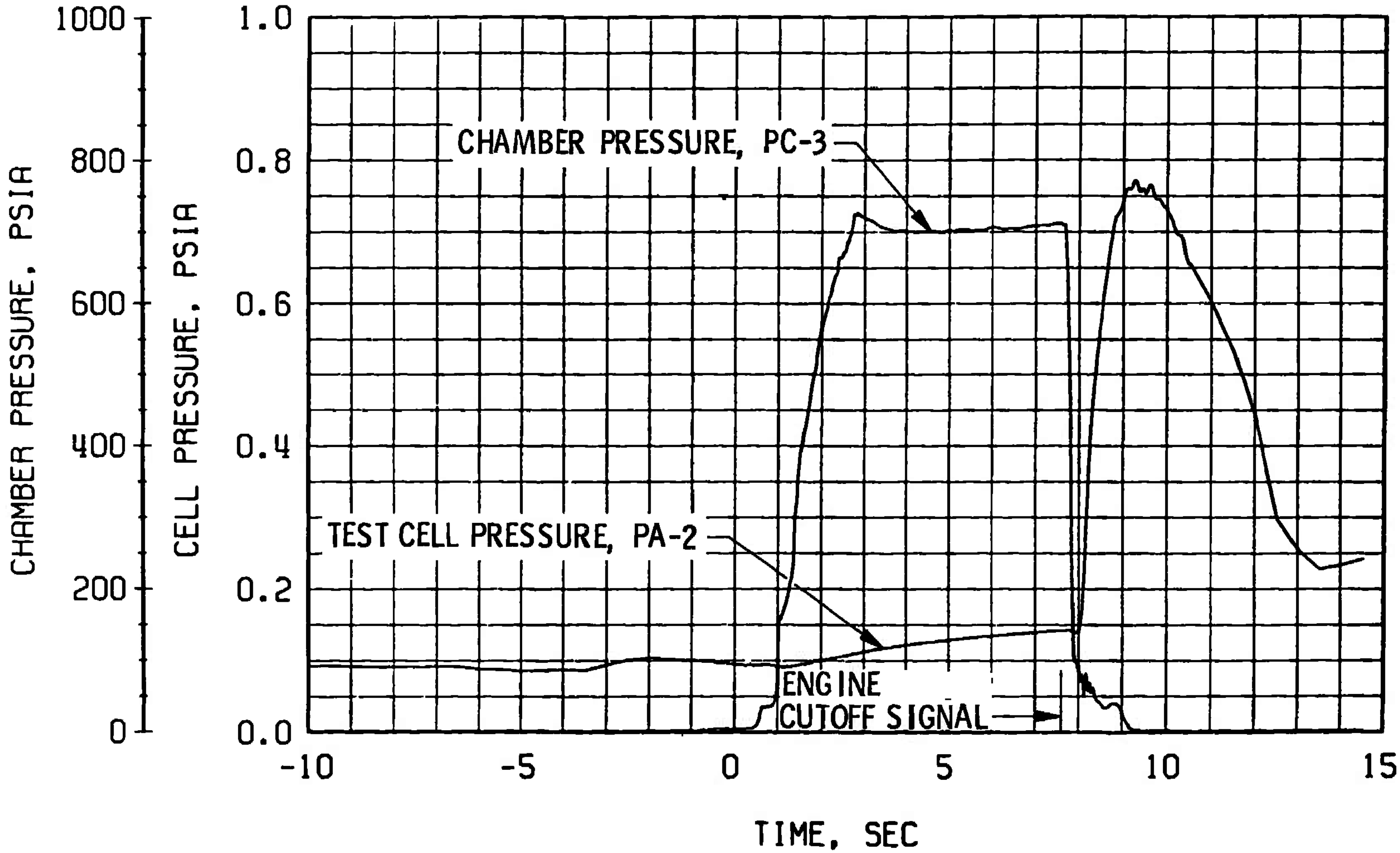
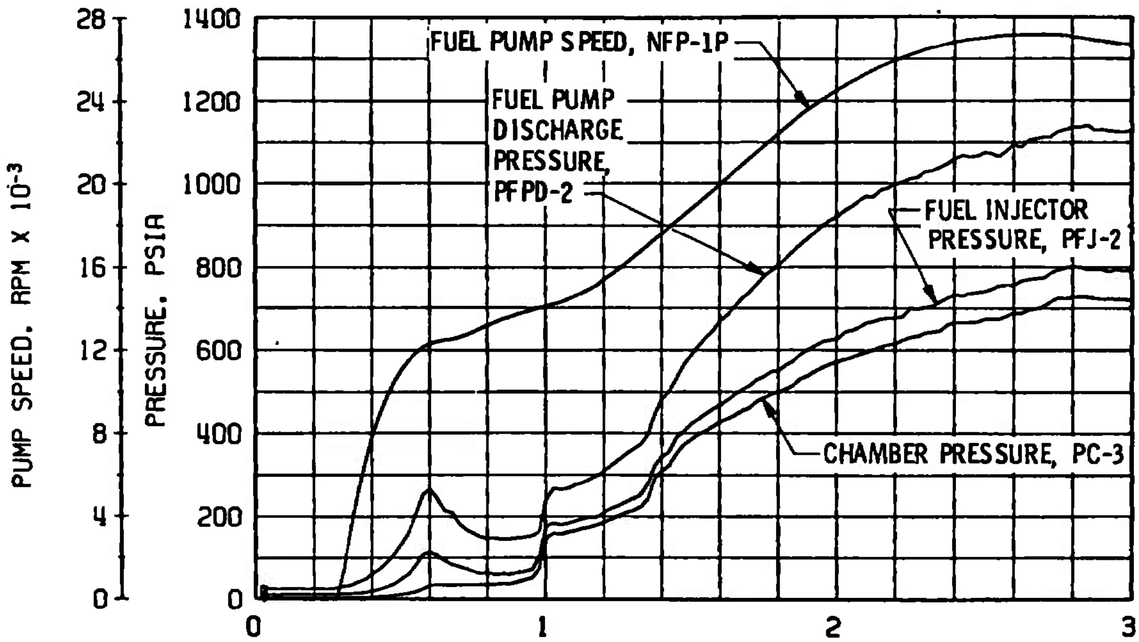
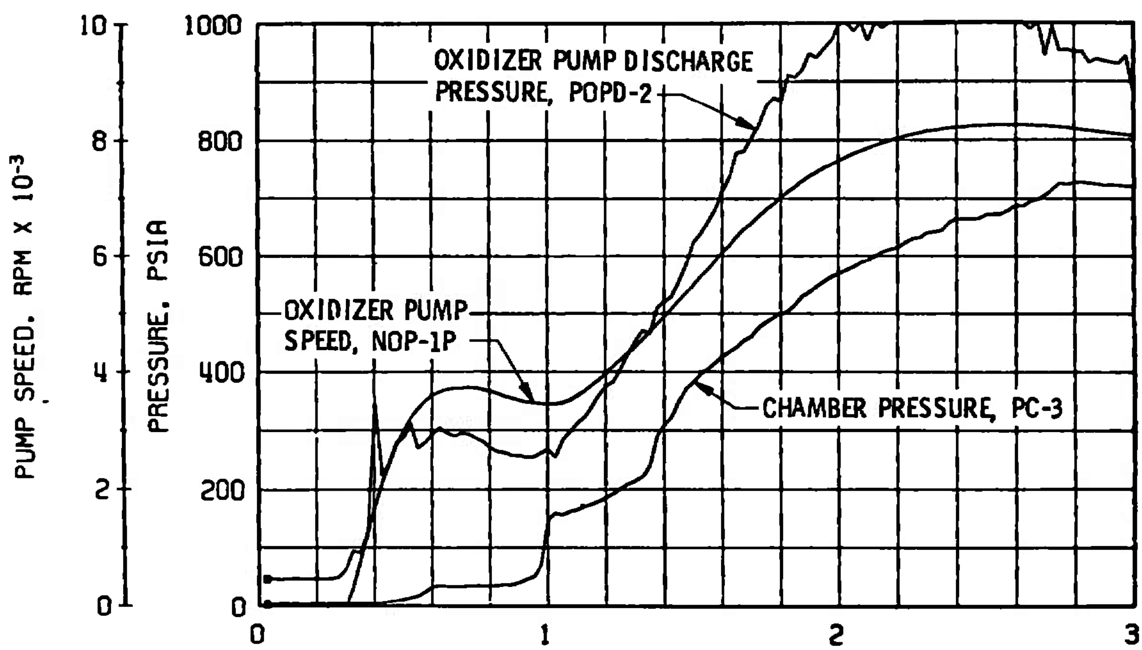


Fig. 121 Engine Ambient and Combustion Chamber Pressures, Firing 33C

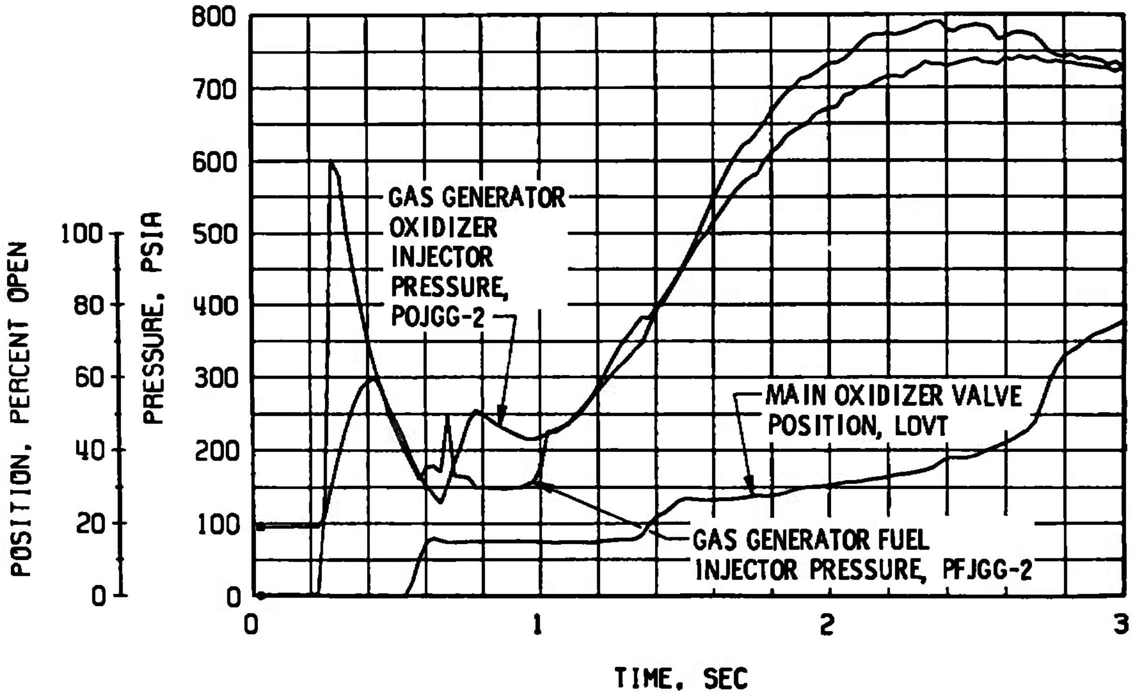


a. Thrust Chamber Fuel System, Start

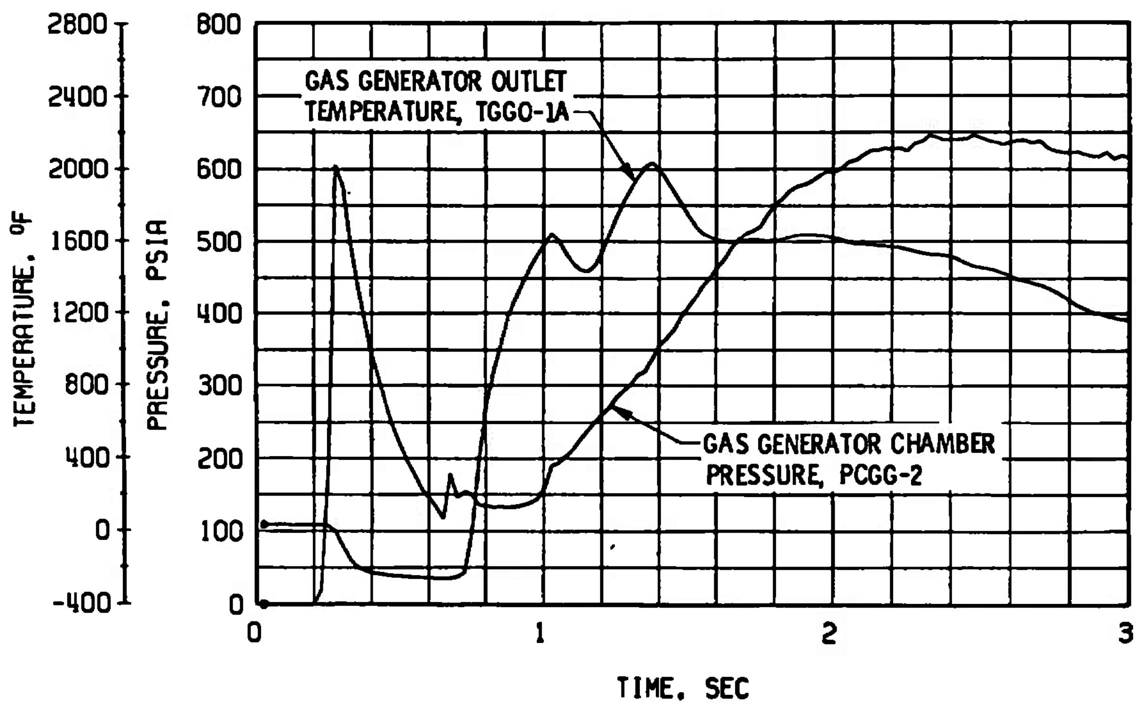


b. Thrust Chamber Oxidizer System, Start

Fig. 122 Engine Transient Operation, Firing 33C

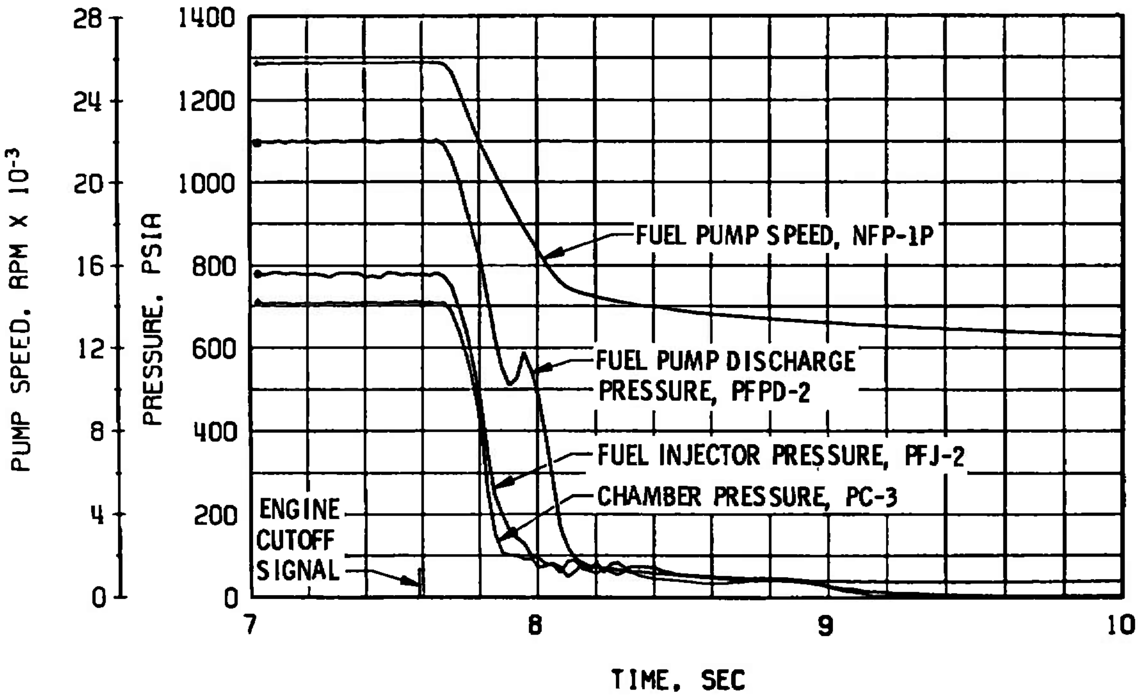


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

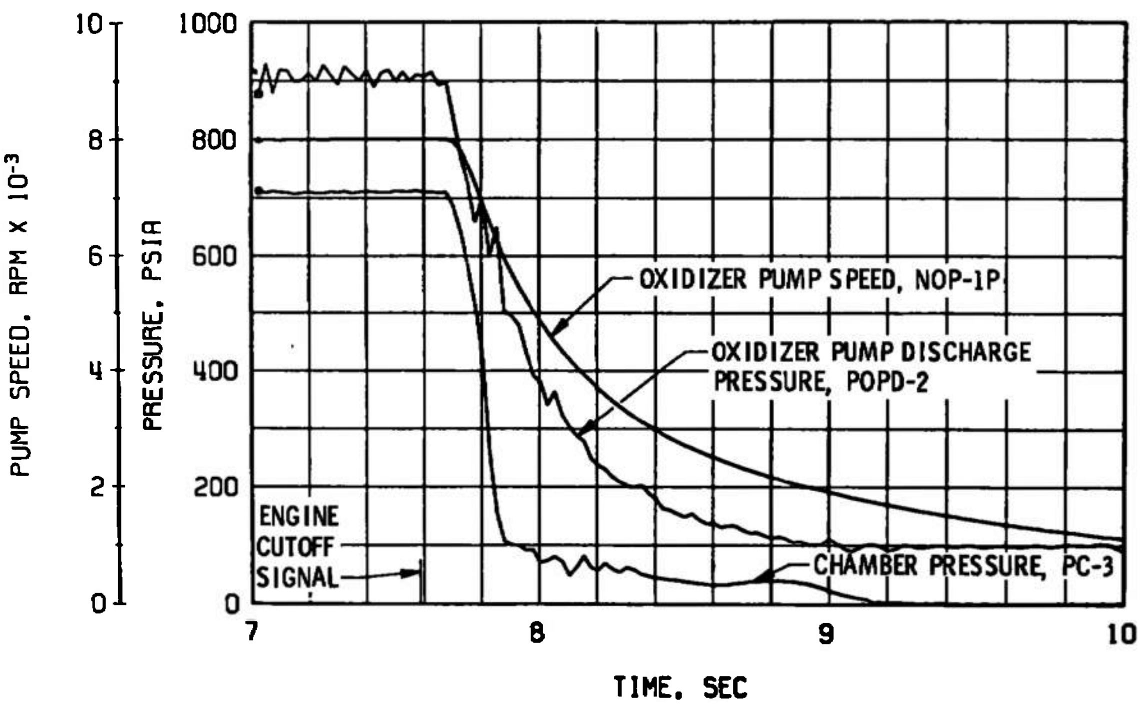


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 122 Continued

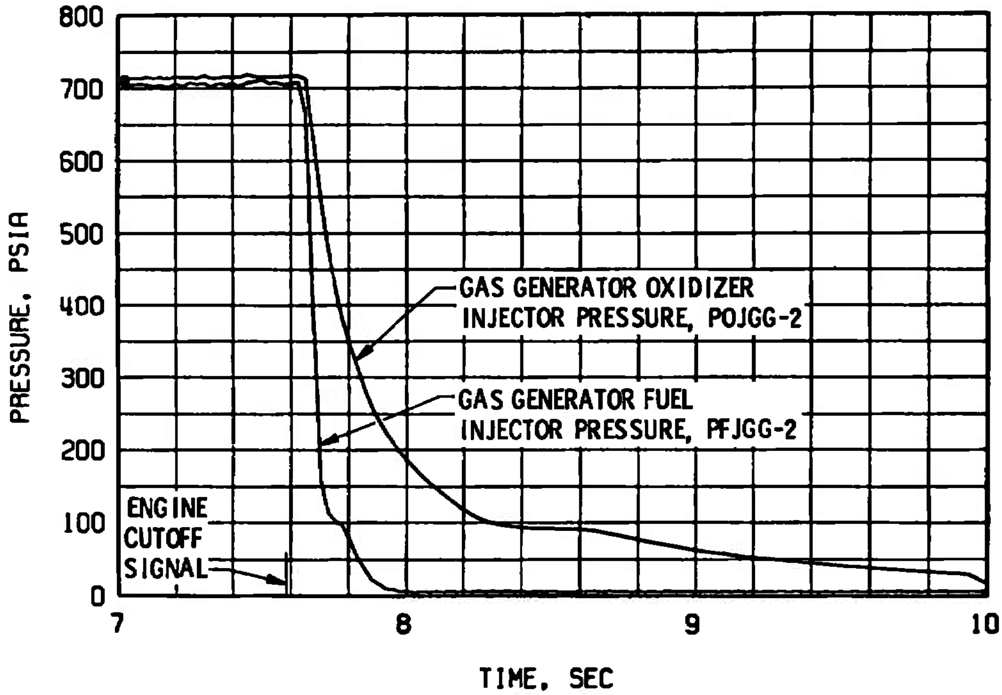


e. Thrust Chamber Fuel System, Shutdown

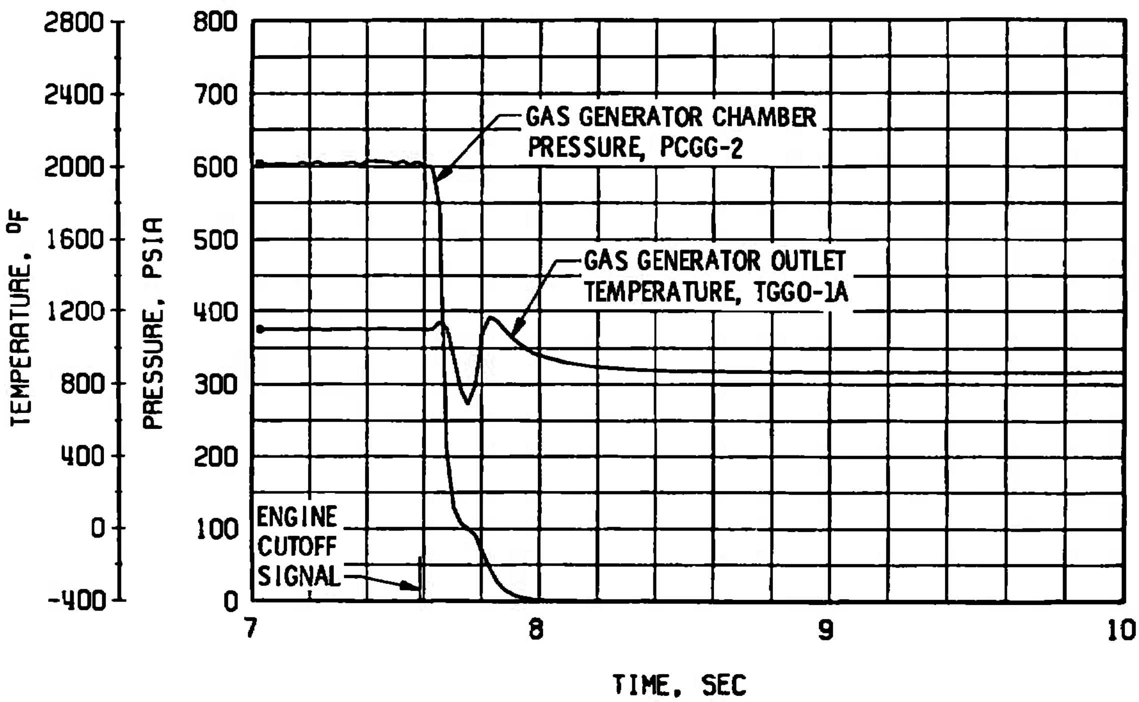


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 122 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 122 Concluded

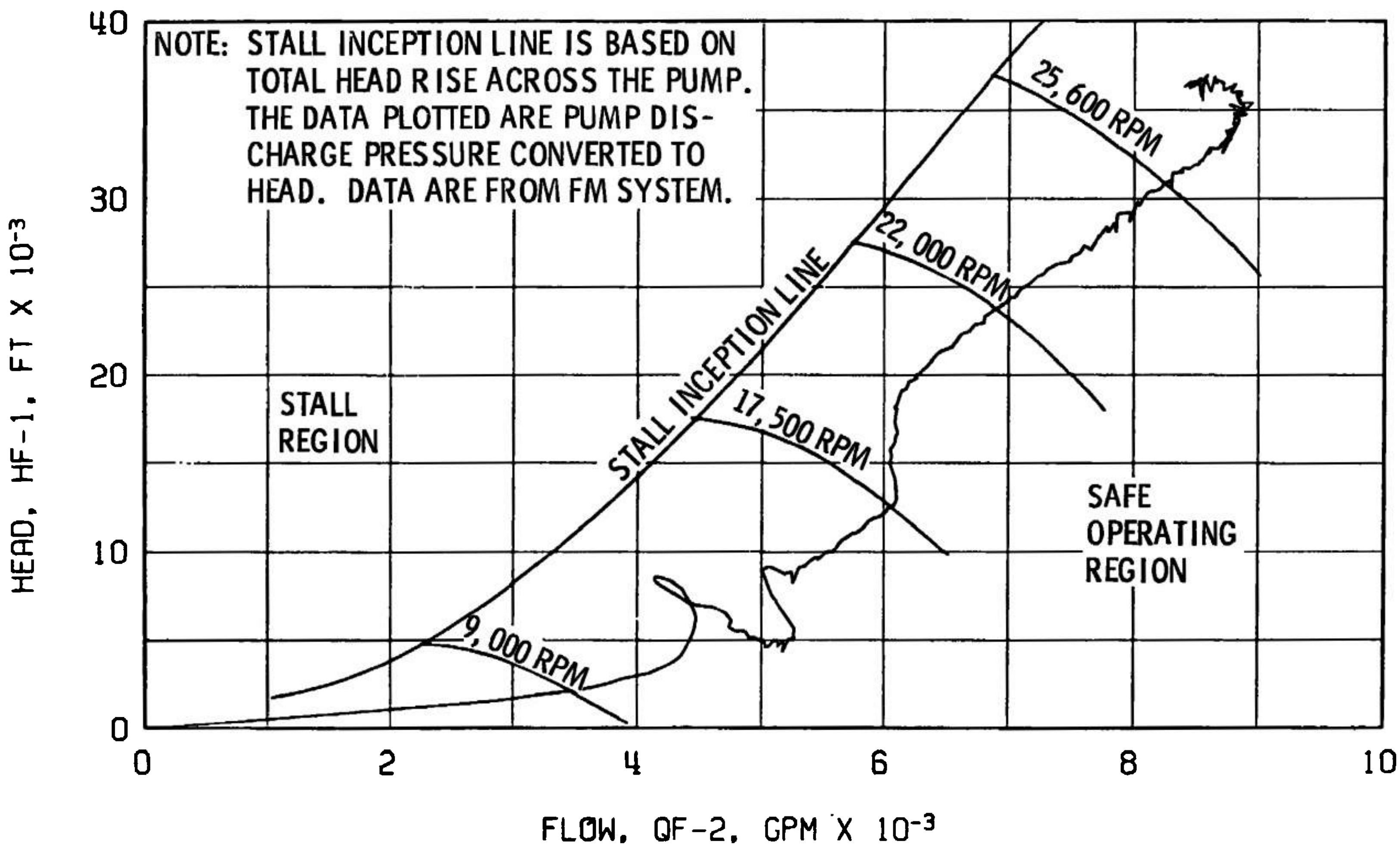
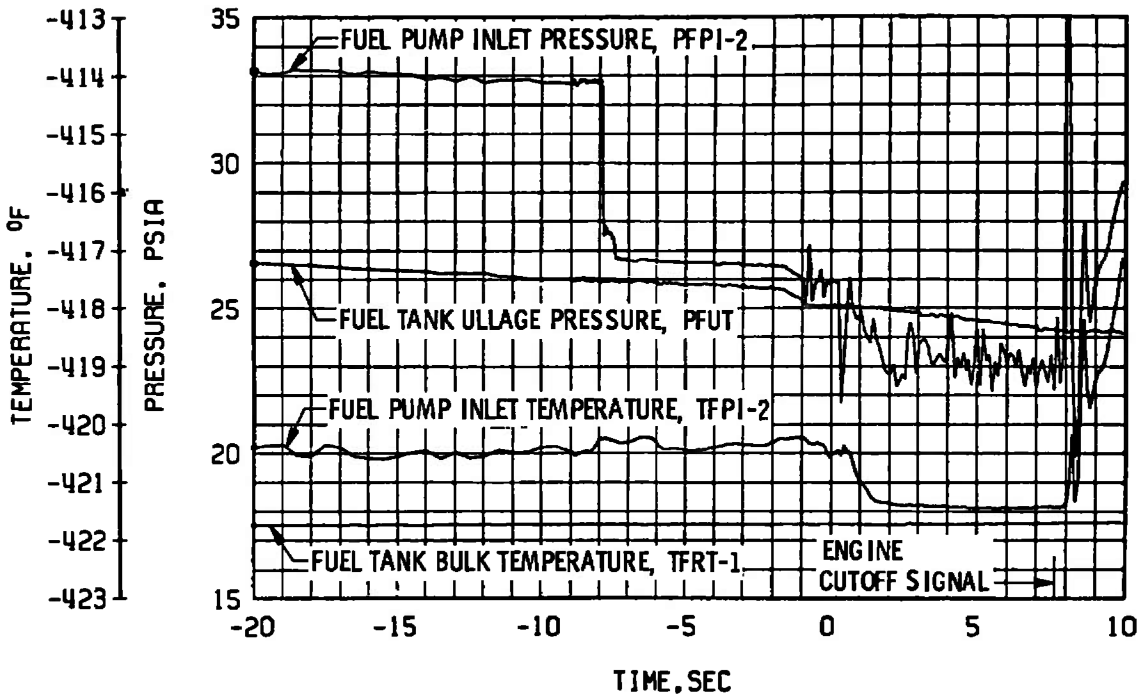
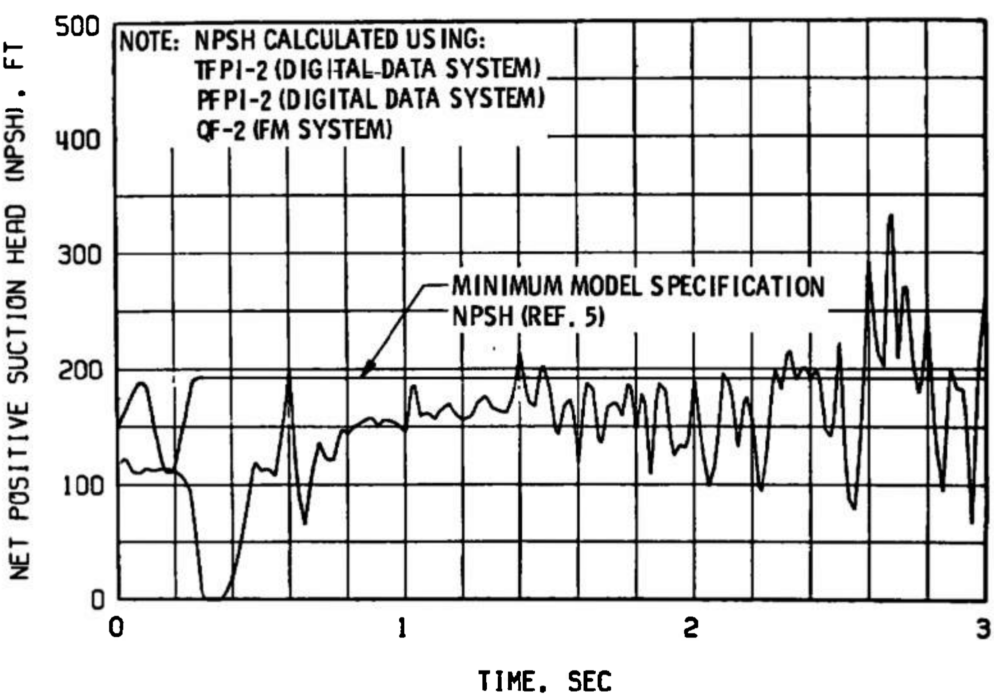


Fig. 123 Fuel Pump Start Transient Performance, Firing 33C

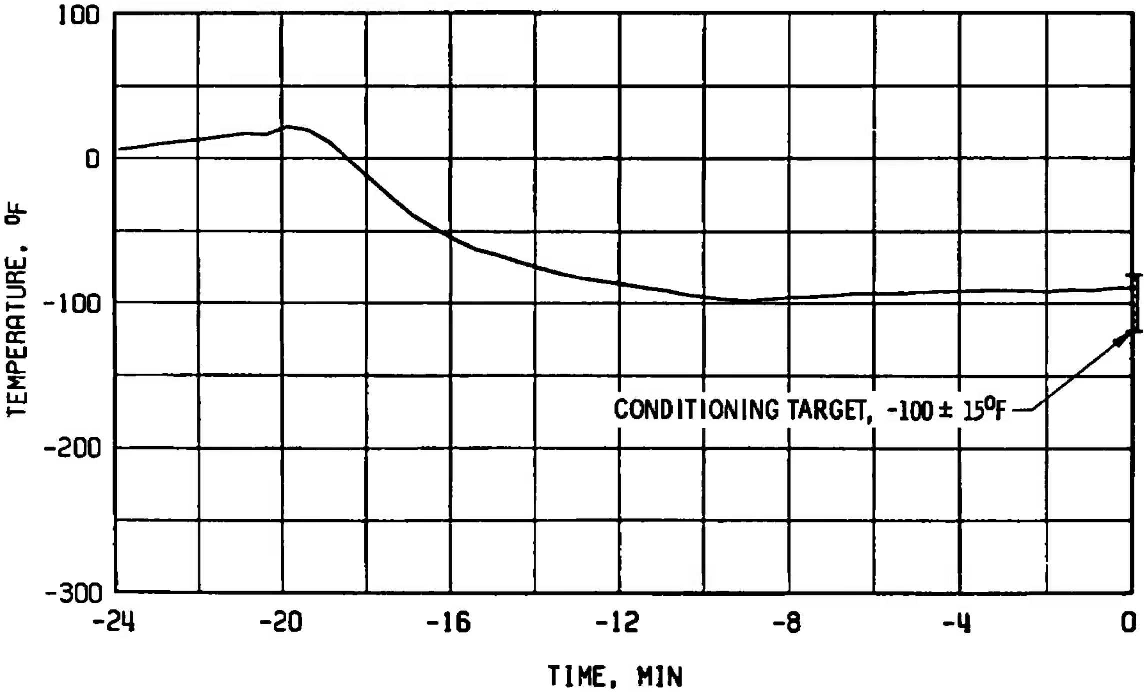


a. Duct Pressure and Temperature Transients

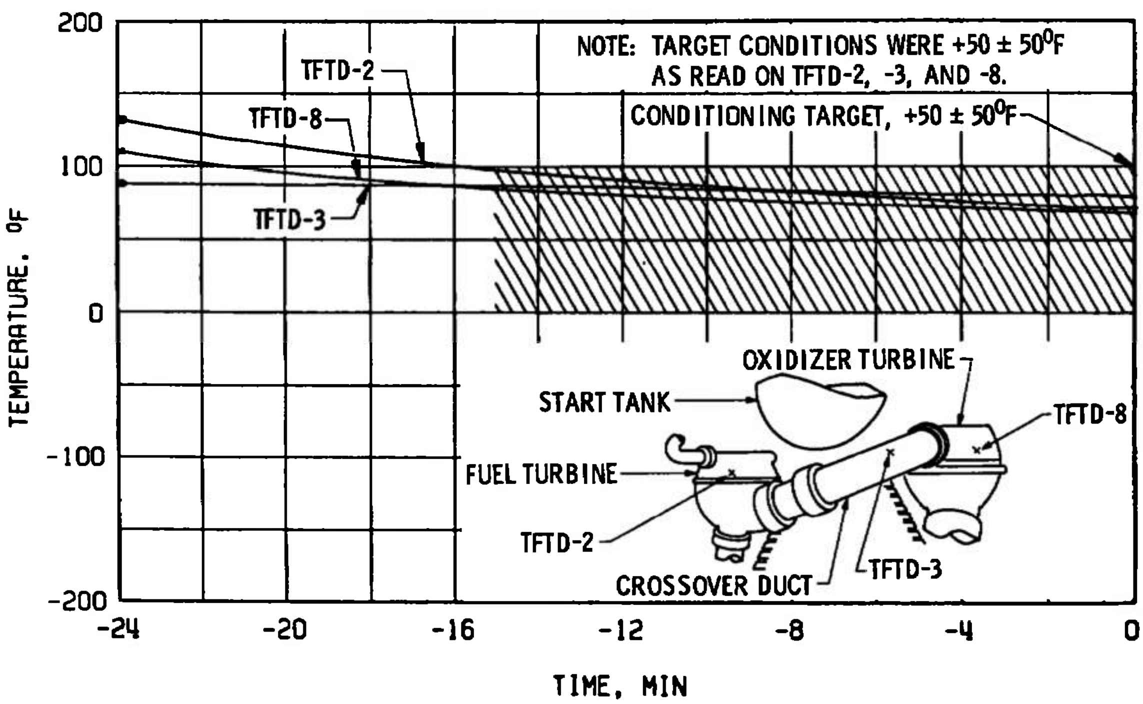


b. Fuel Pump NPSH during Start Transient, Firing 33C

Fig. 124 Fuel Low Pressure Duct Performance, Firing 33C

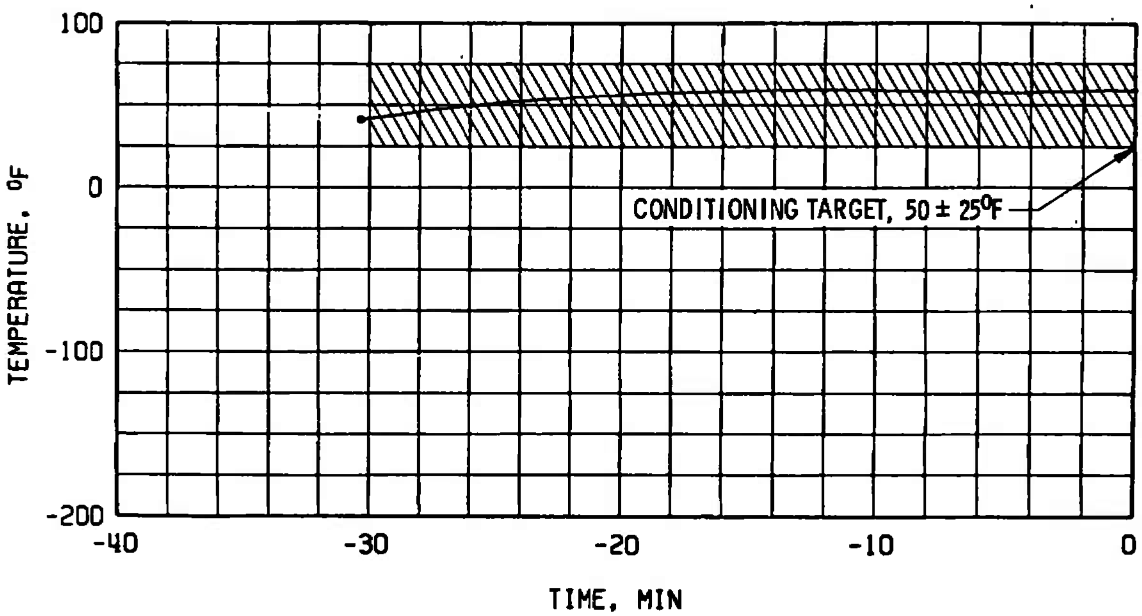


a. Thrust Chamber Throat, TTC-1P

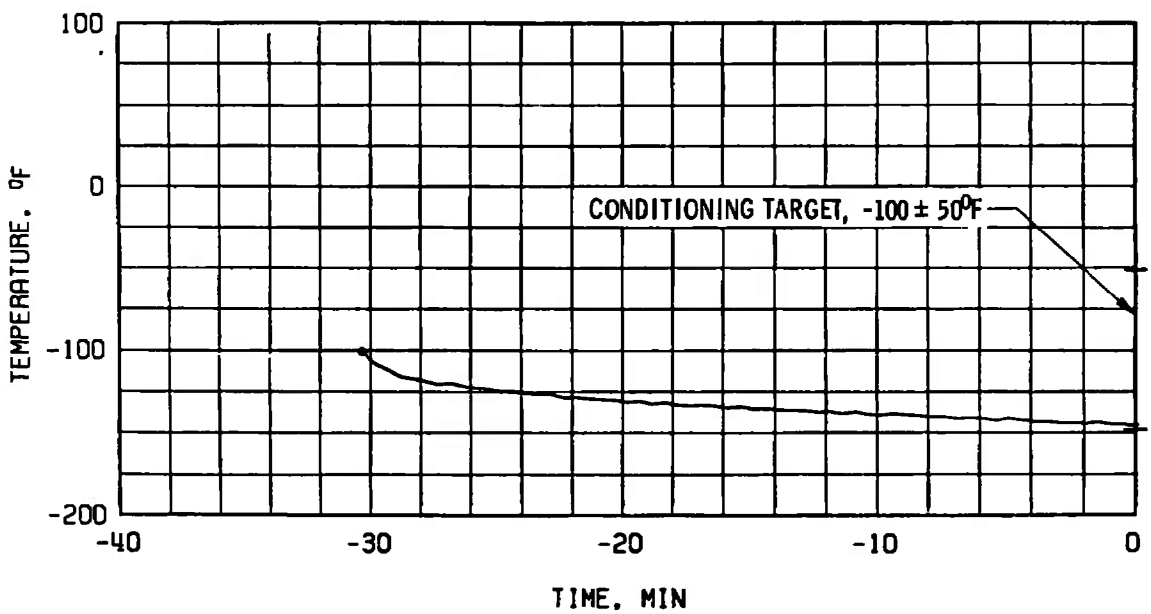


b. Crossover Duct, TFTD

Fig. 125 Thermal Conditioning History of Engine Components, Firing 33D



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 125 Concluded

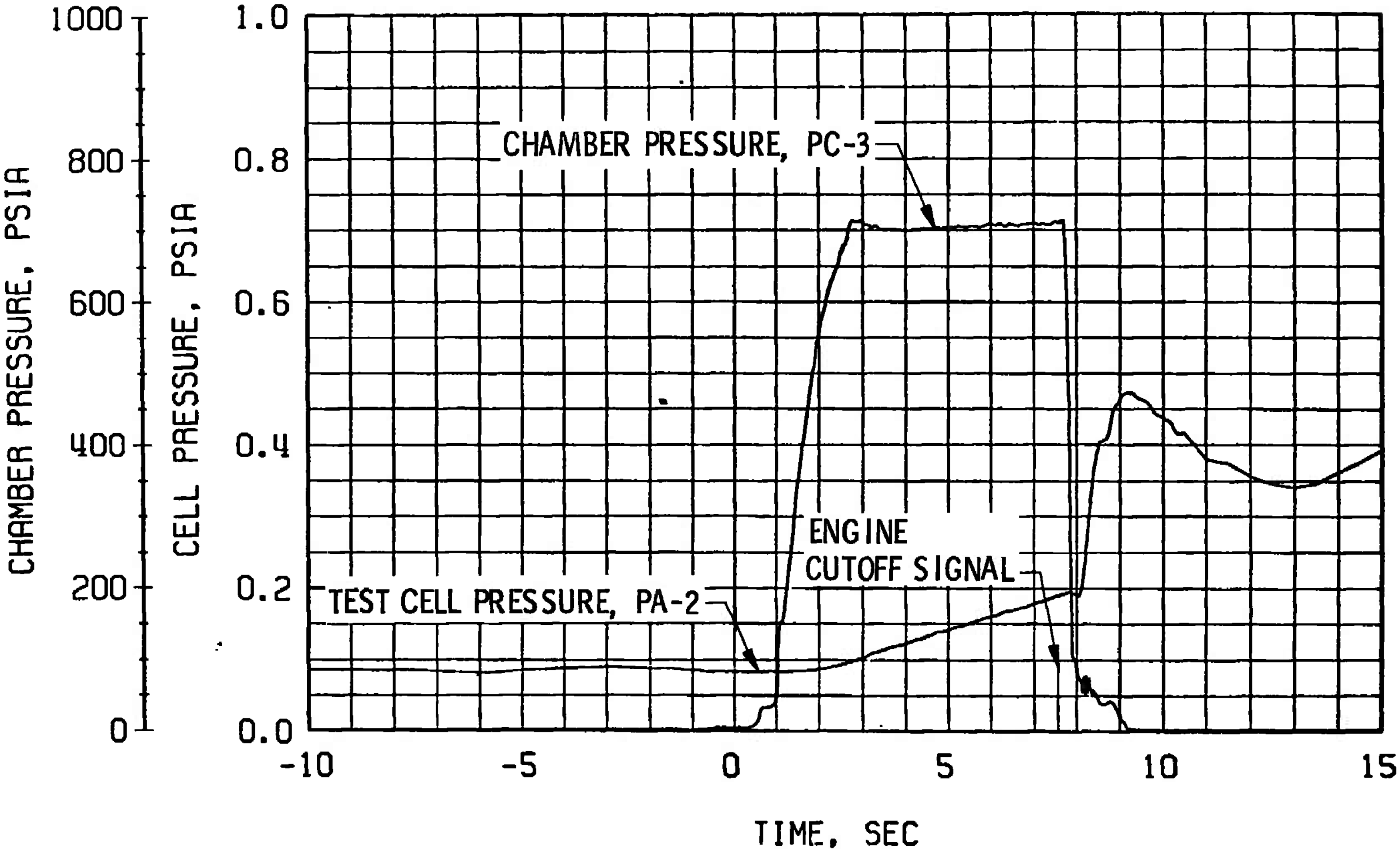
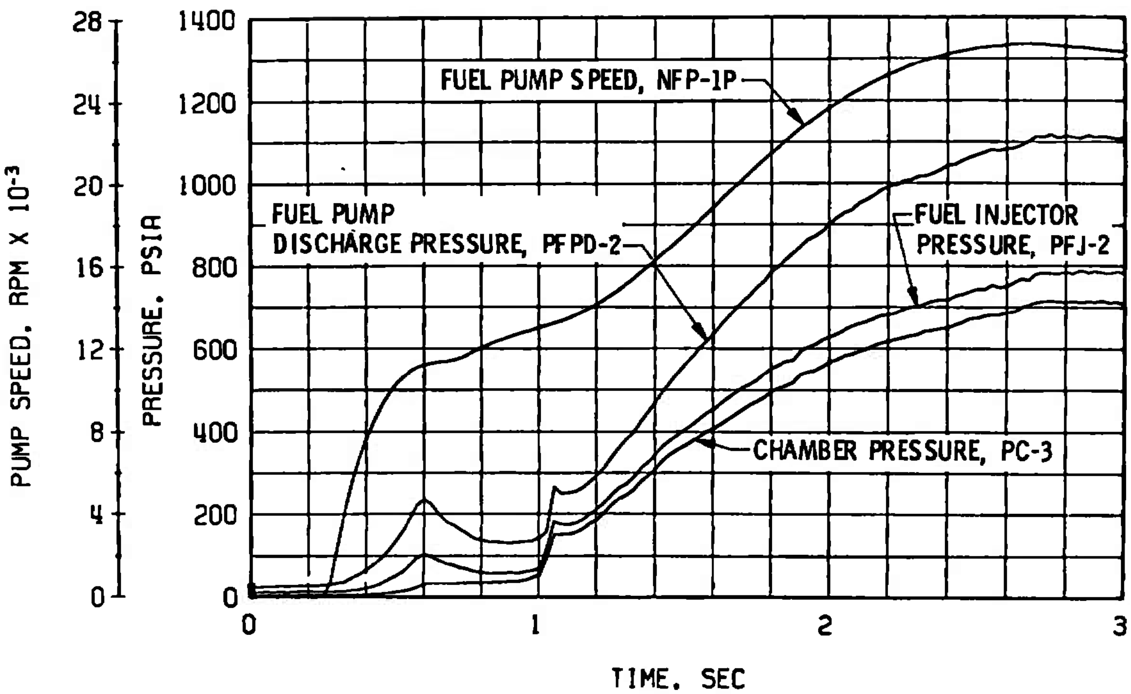
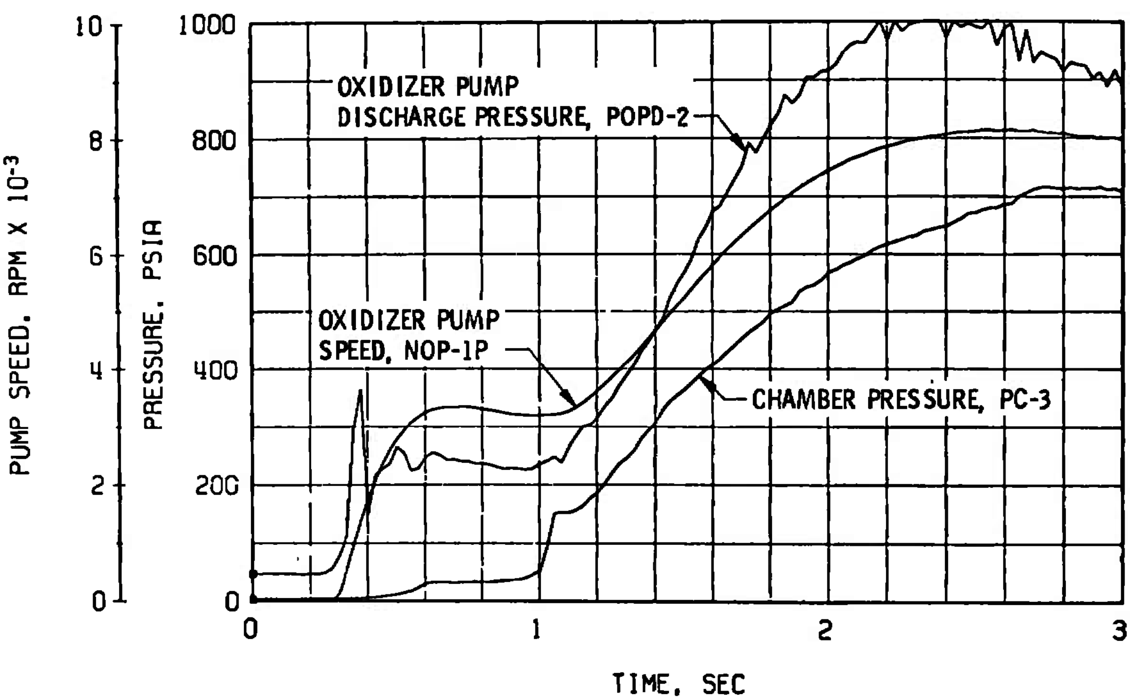


Fig. 126 Engine Ambient and Combustion Chamber Pressures, Firing 33D

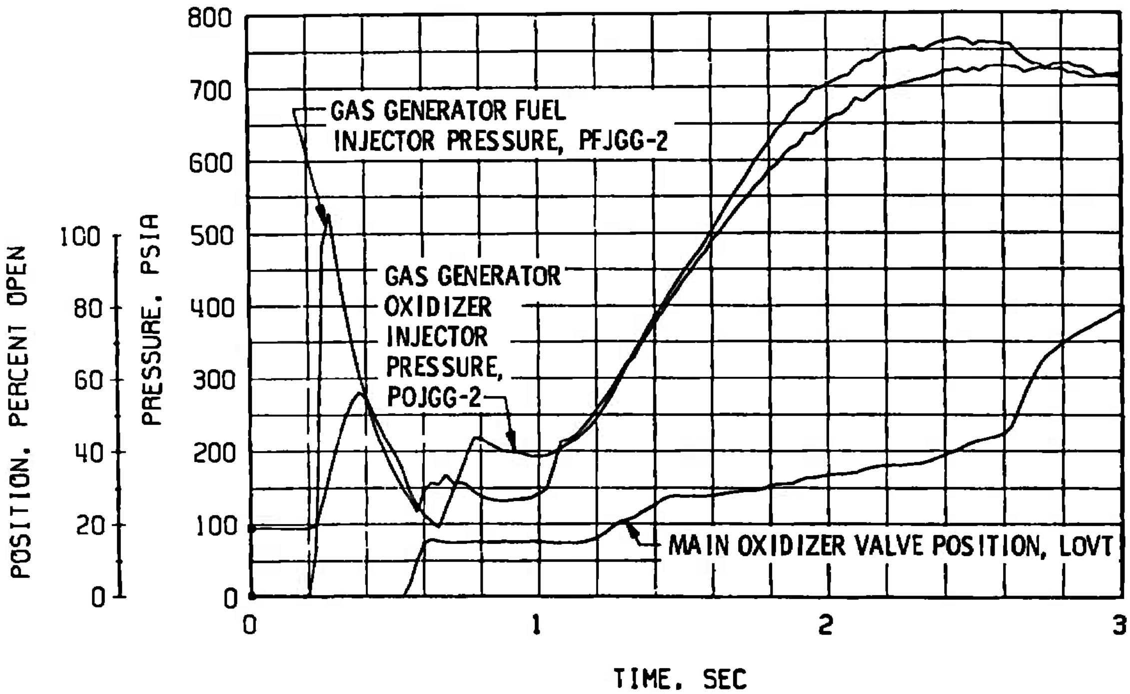


a. Thrust Chamber Fuel System, Start

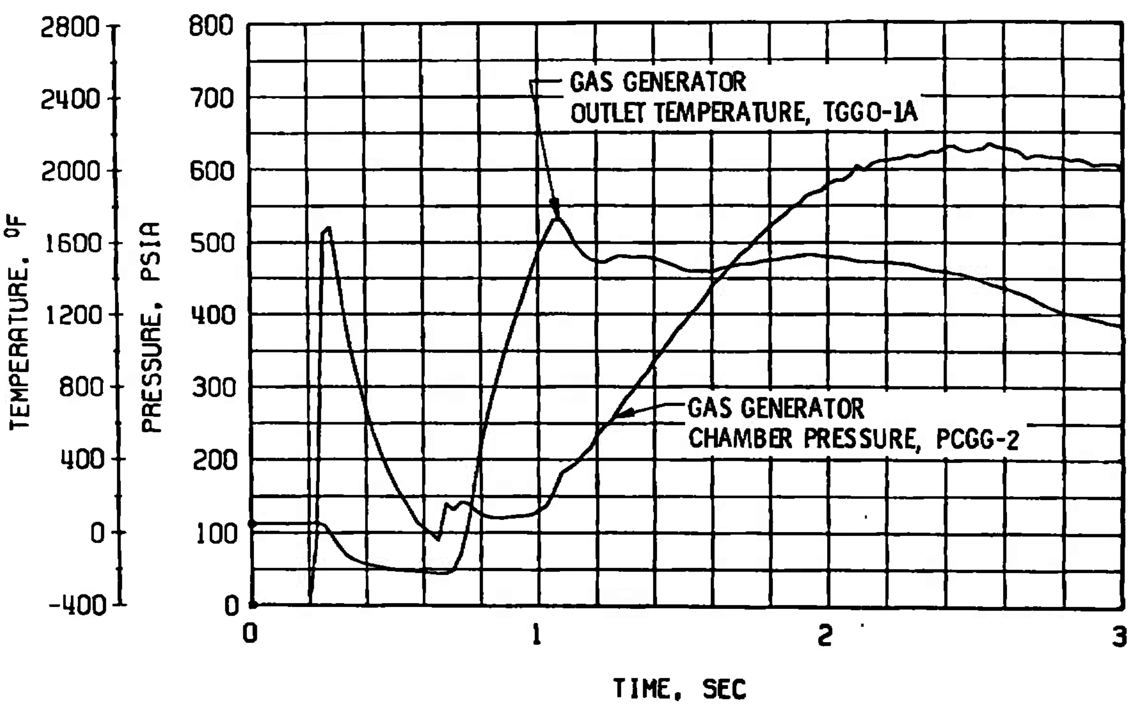


b. Thrust Chamber Oxidizer System, Start

Fig. 127 Engine Transient Operation, Firing 33D

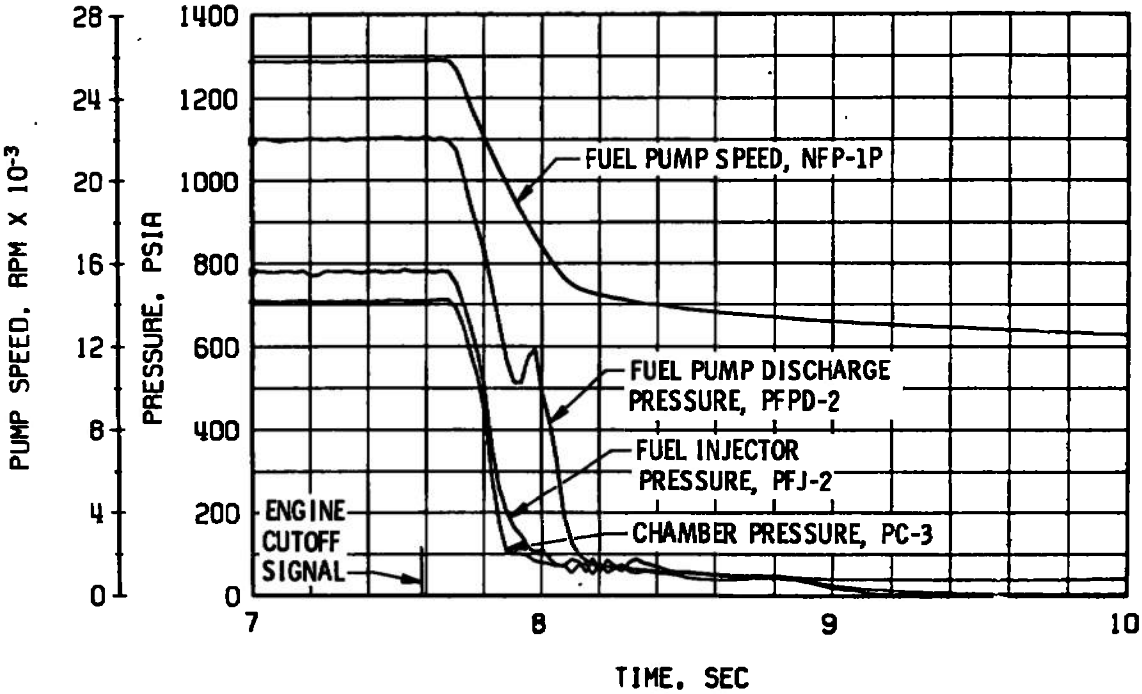


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

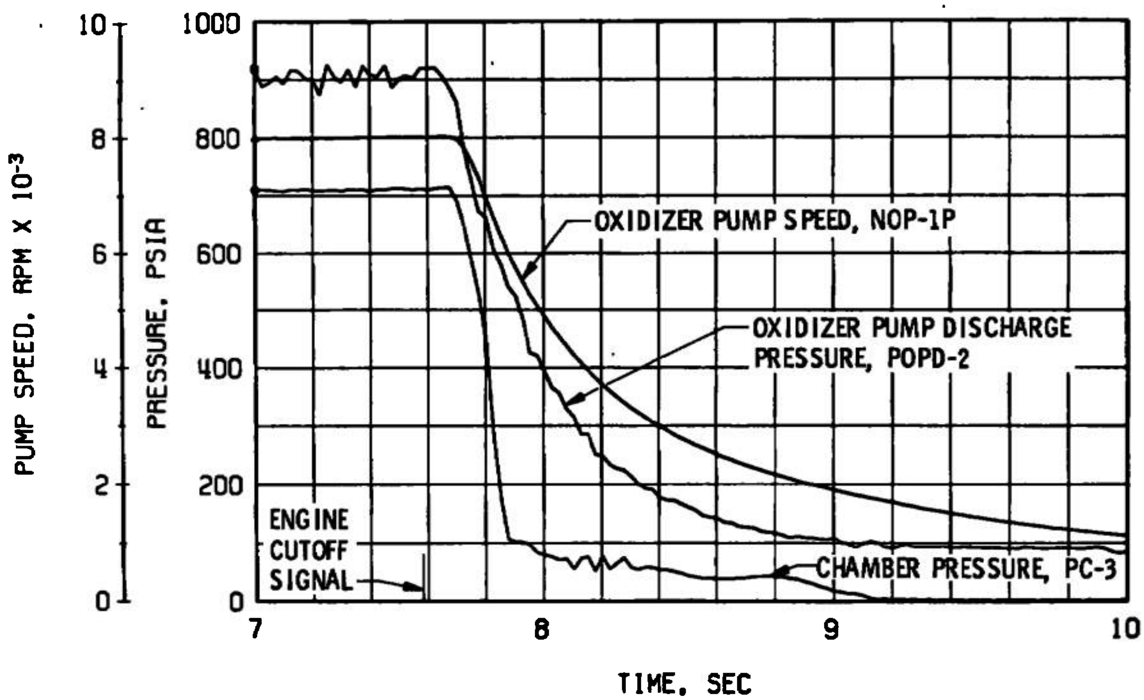


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 127 Continued

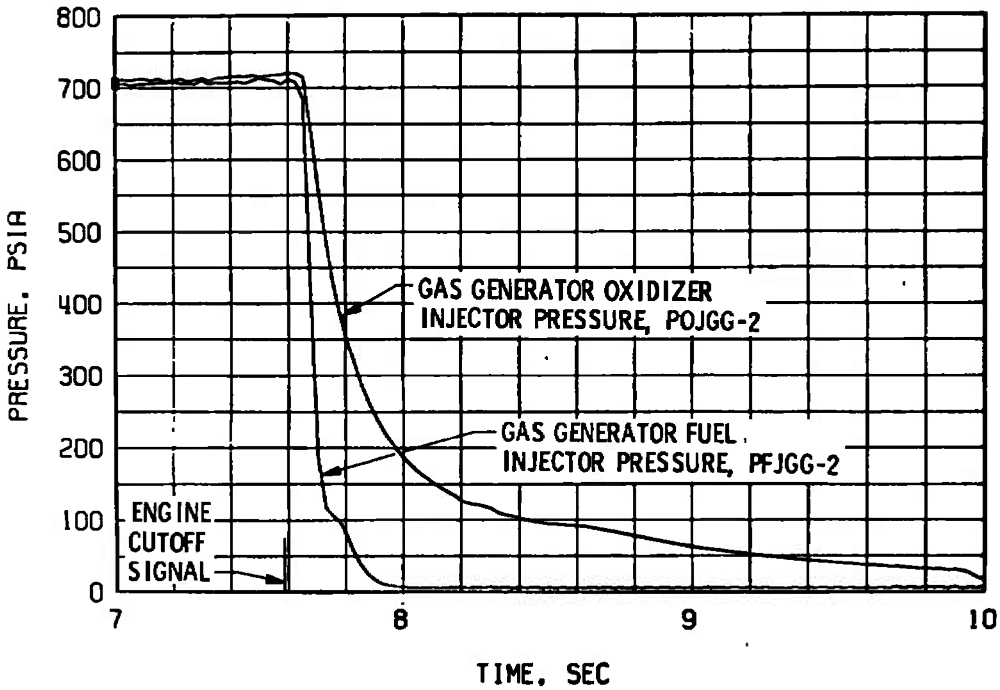


e. Thrust Chamber Fuel System, Shutdown

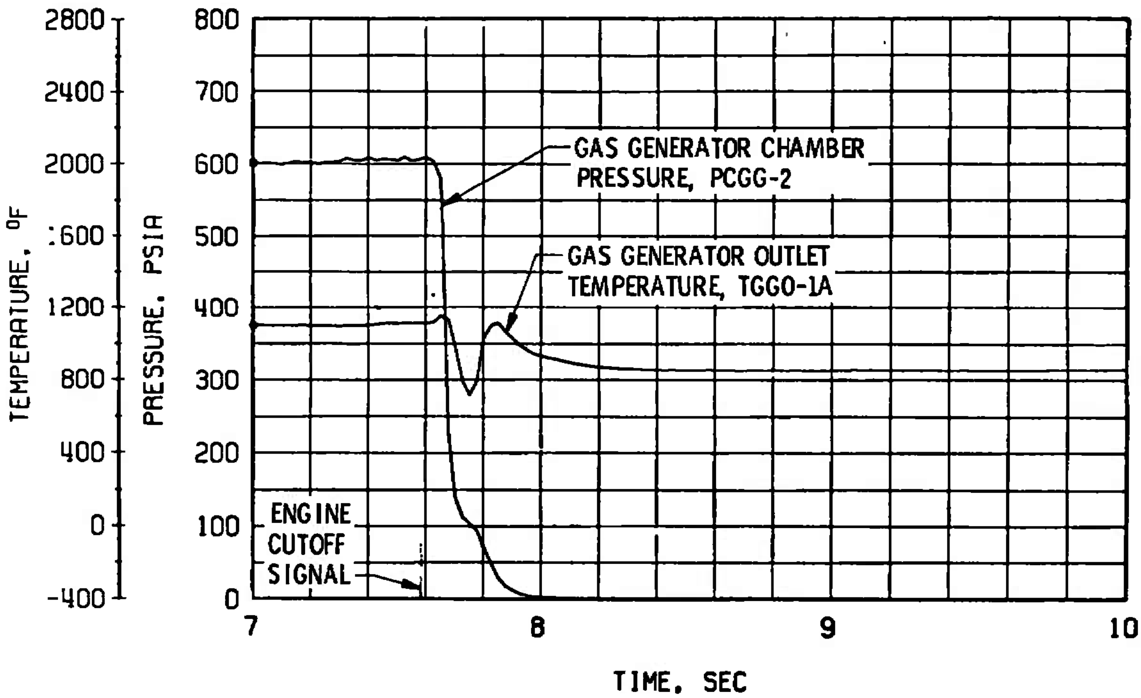


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 127 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 127 Concluded

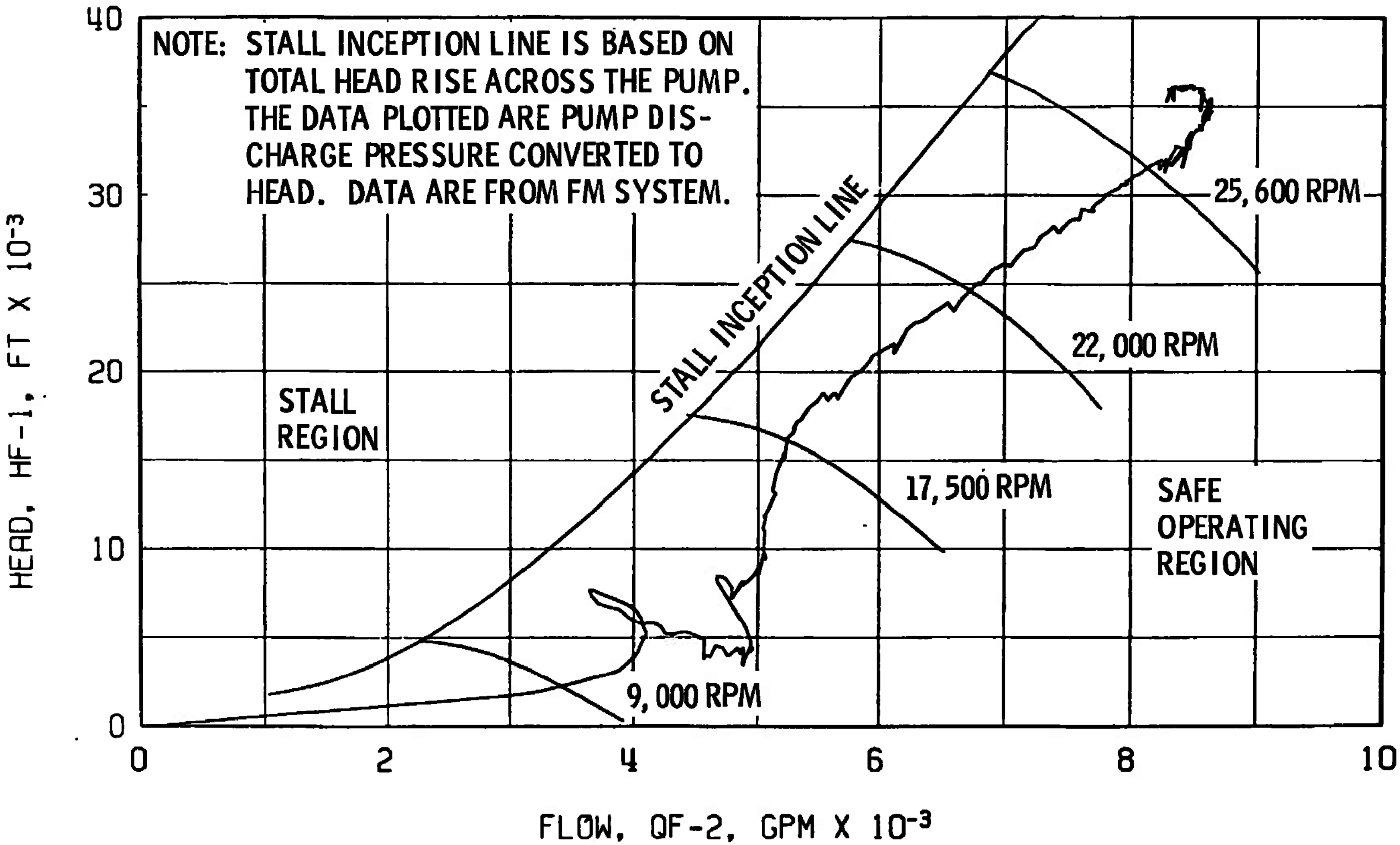
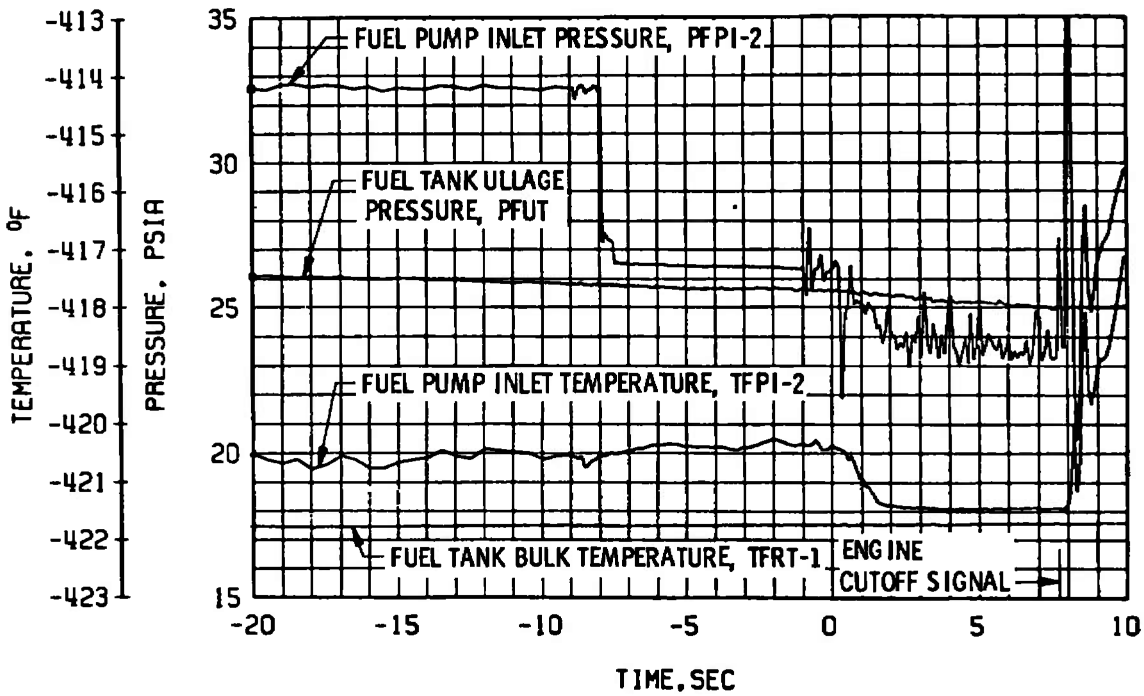
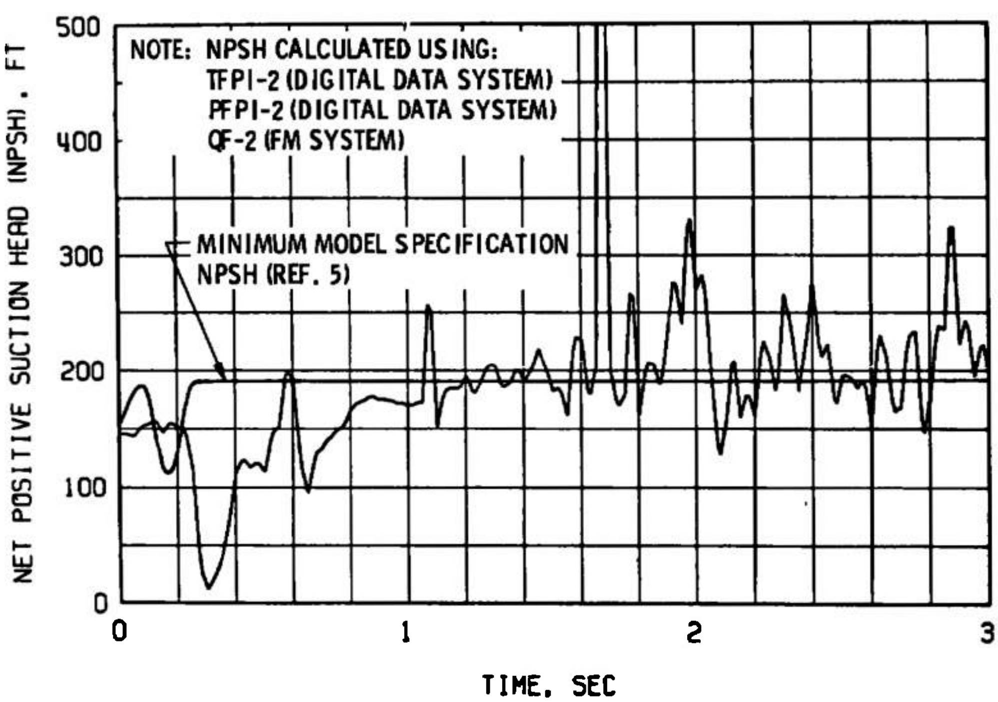


Fig. 128 Fuel Pump Start Transient Performance, Firing 33D

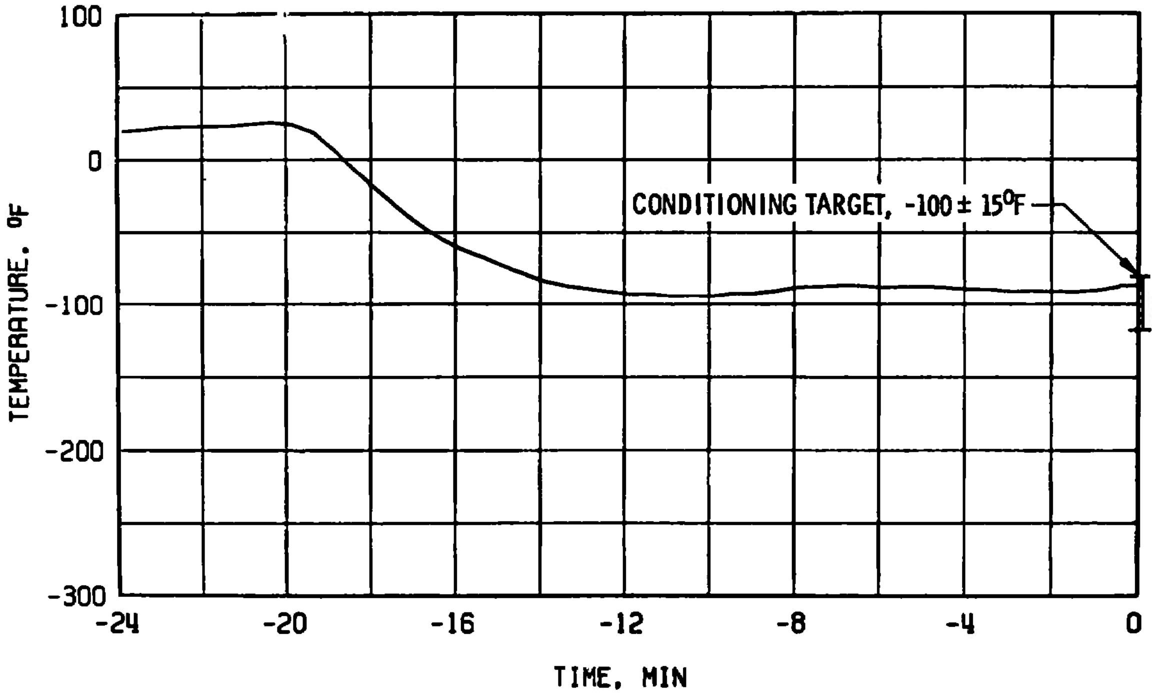


a. Duct Pressure and Temperature Transients

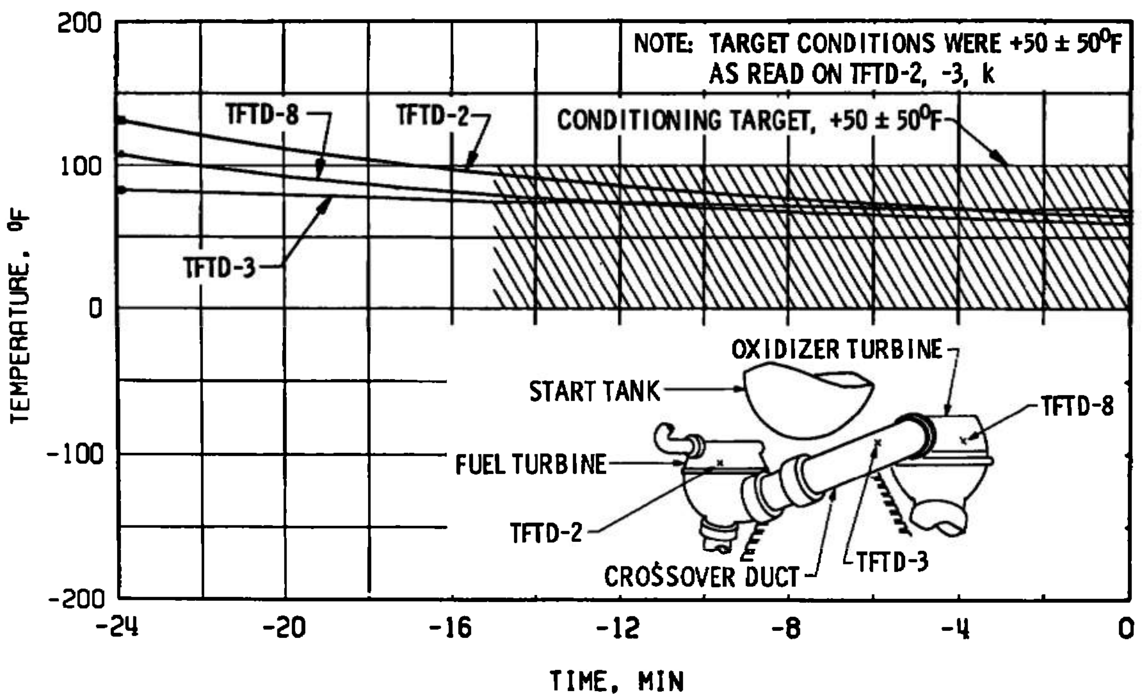


b. Fuel Pump NPSH during Start Transient, Firing 33D

Fig. 129 Fuel Low Pressure Duct Performance, Firing 33D

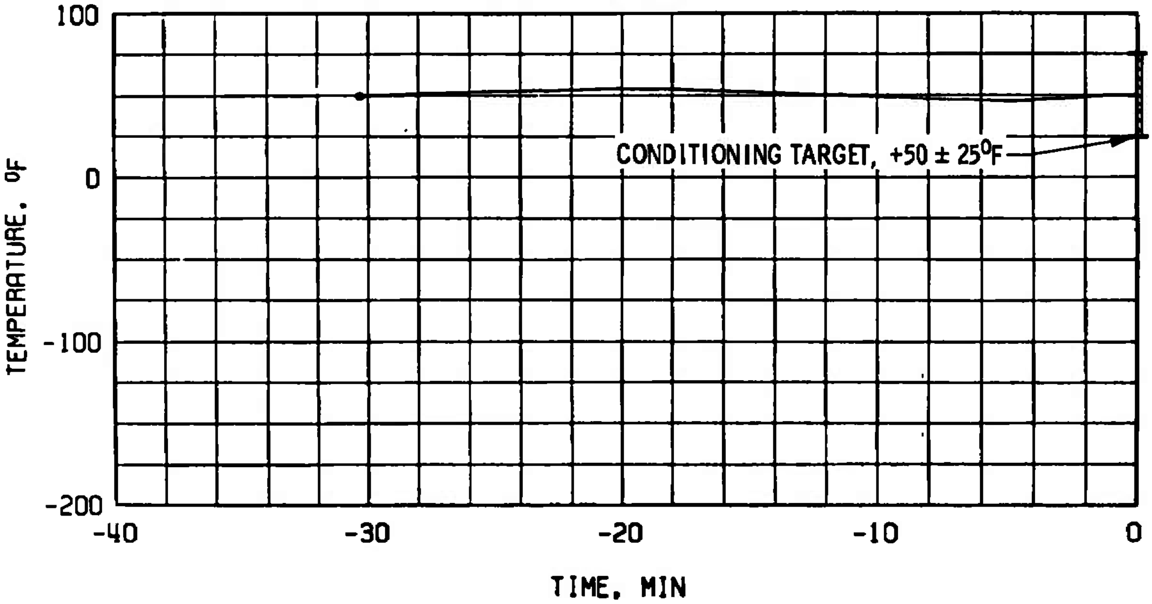


a. Thrust Chamber Throat, TTC-1P

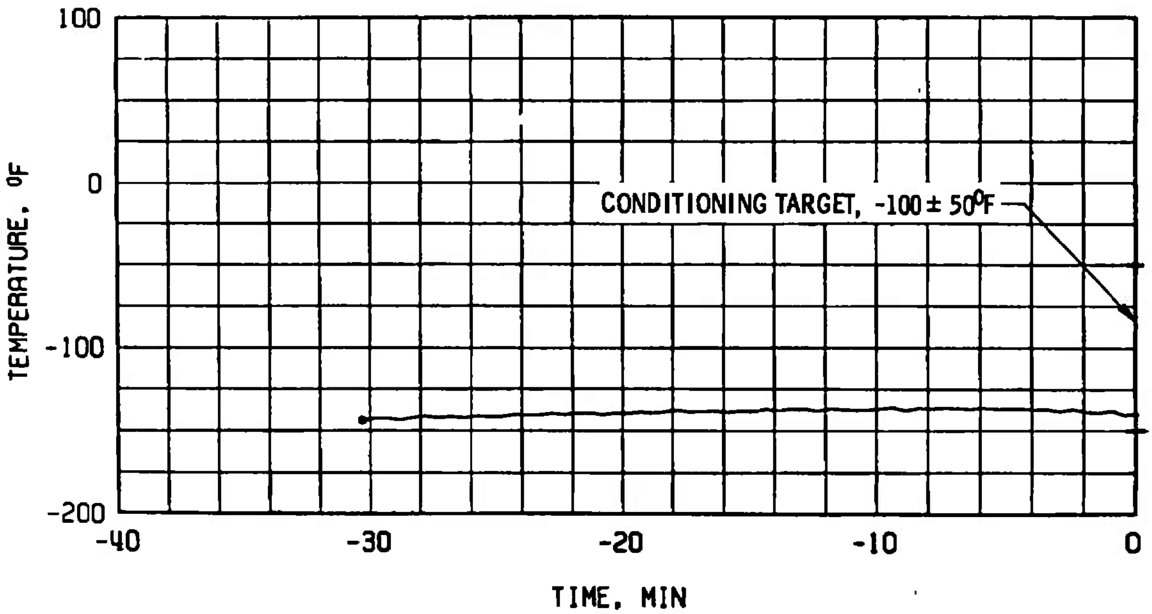


b. Crossover Duct, TFTD

Fig. 130 Thermal Conditioning History of Engine Components, Firing 33E



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 130 Concluded

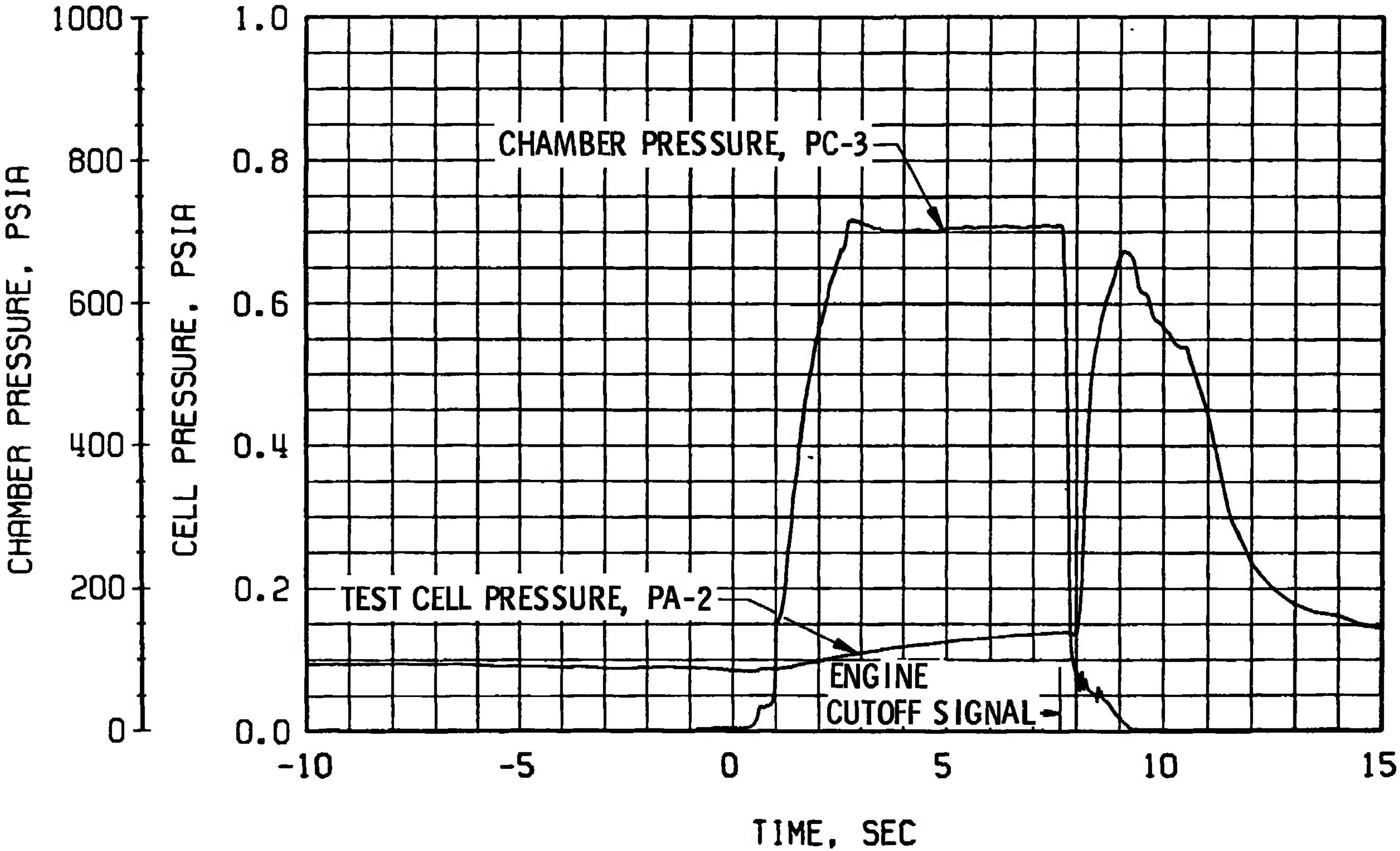
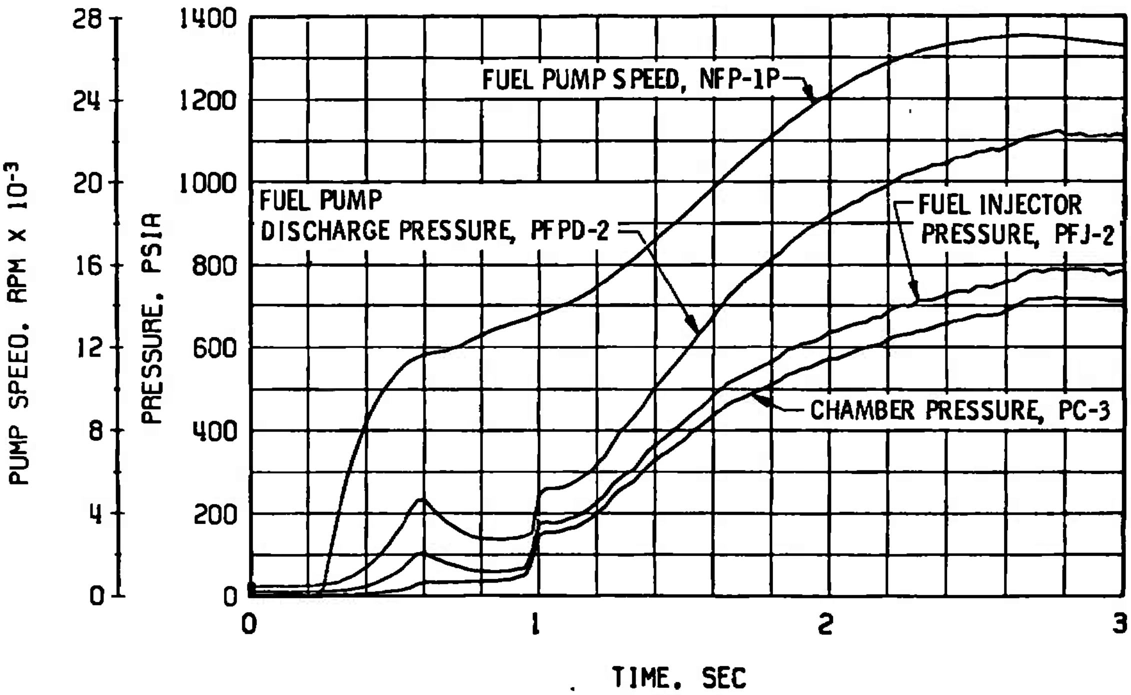
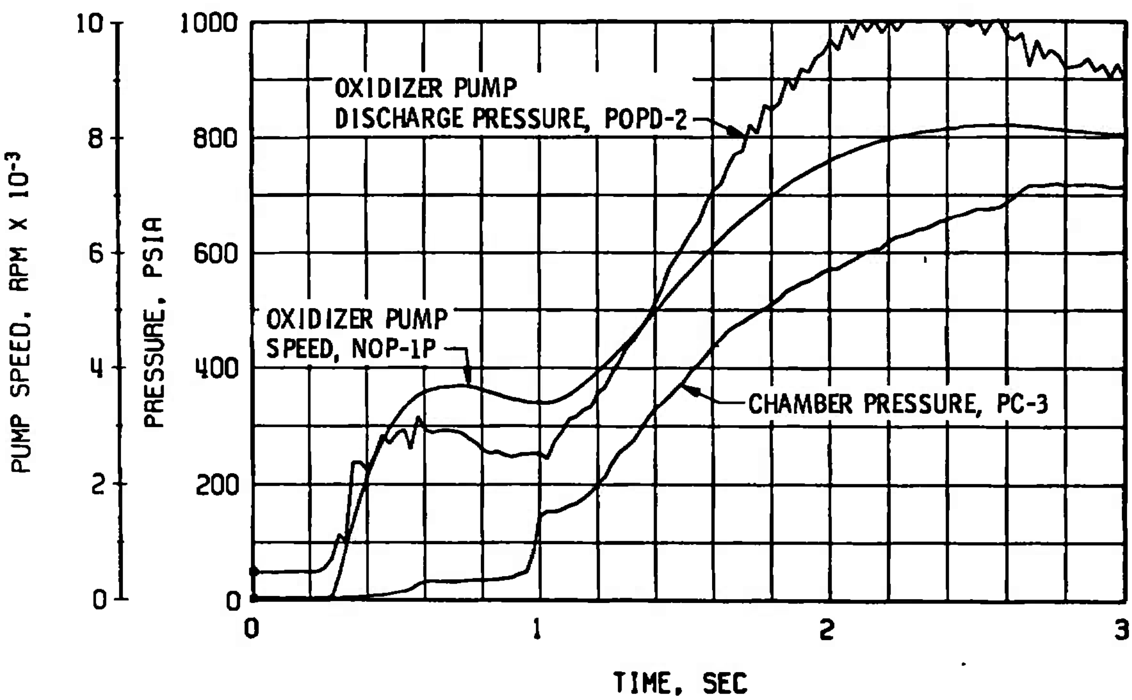


Fig. 131 Engine Ambient and Combustion Chamber Pressures, Firing 33E

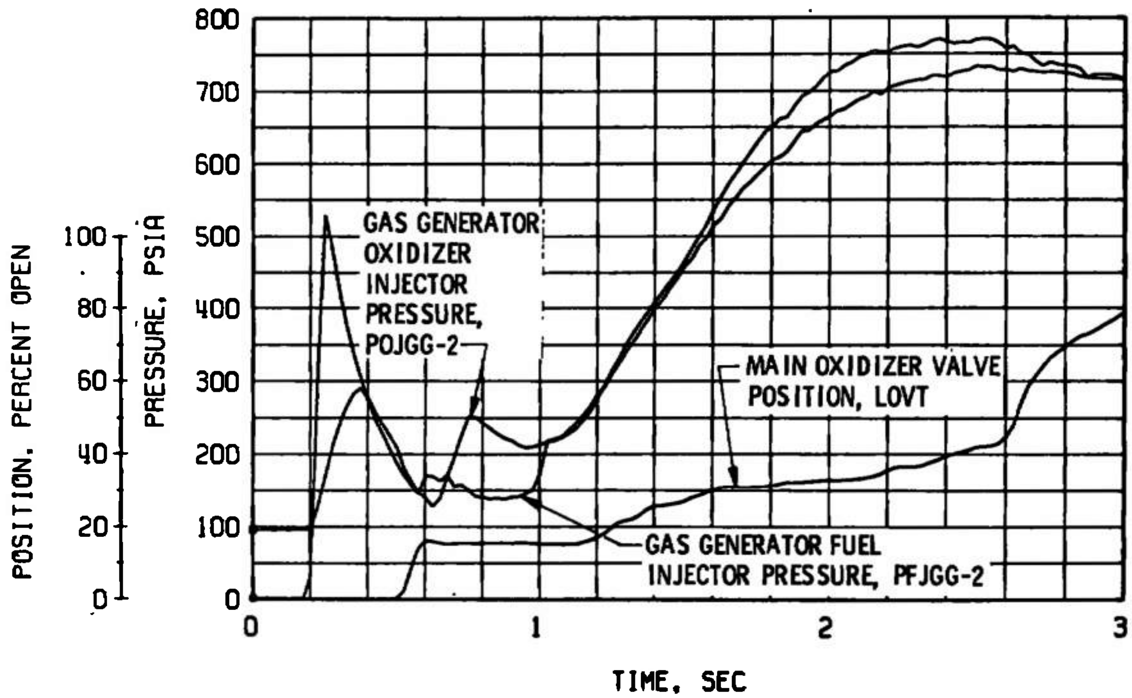


a. Thrust Chamber Fuel System, Start

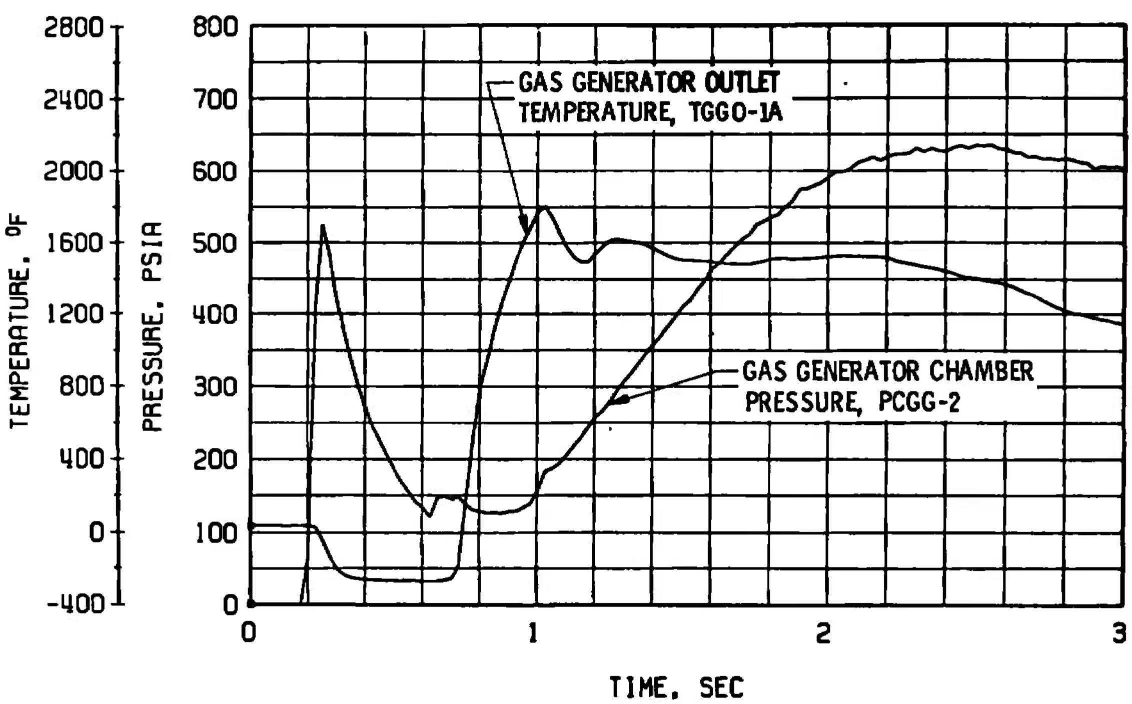


b. Thrust Chamber Oxidizer System, Start

Fig. 132 Engine Transient Operation, Firing 33E

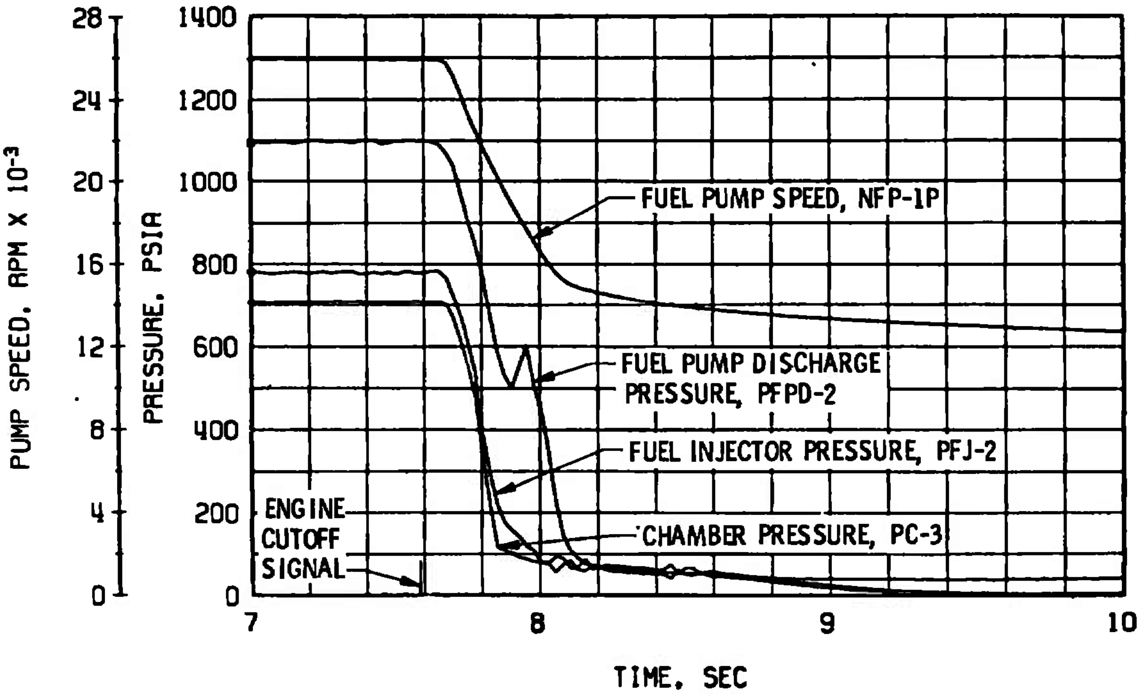


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

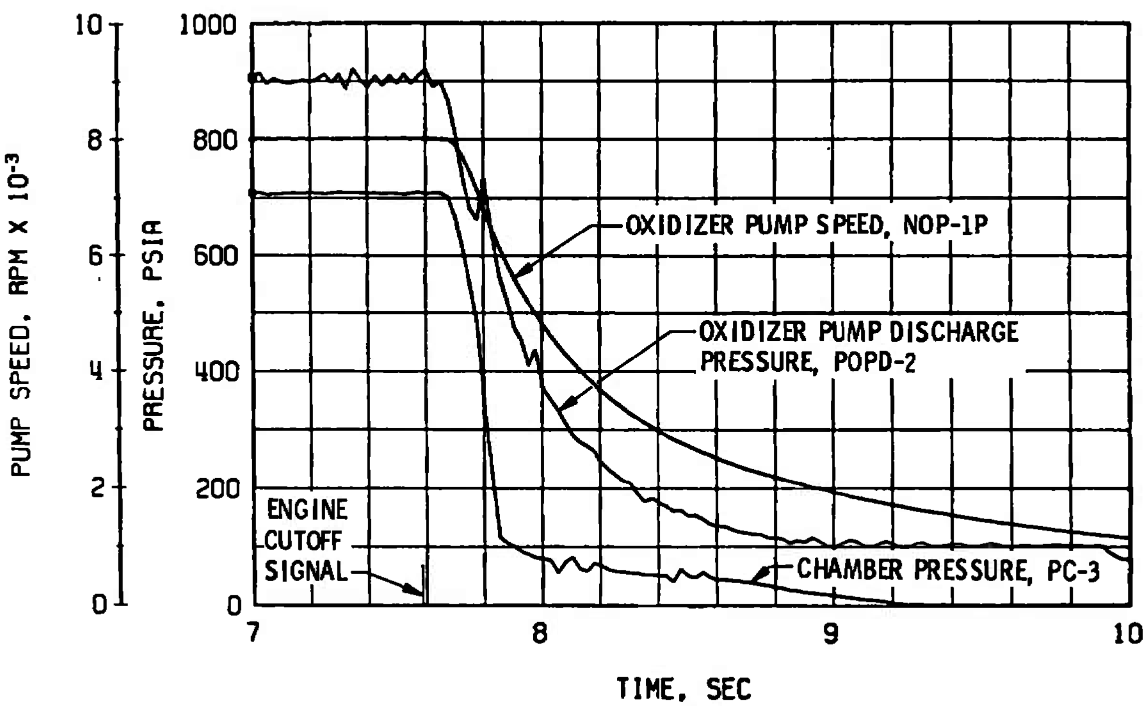


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 132 Continued

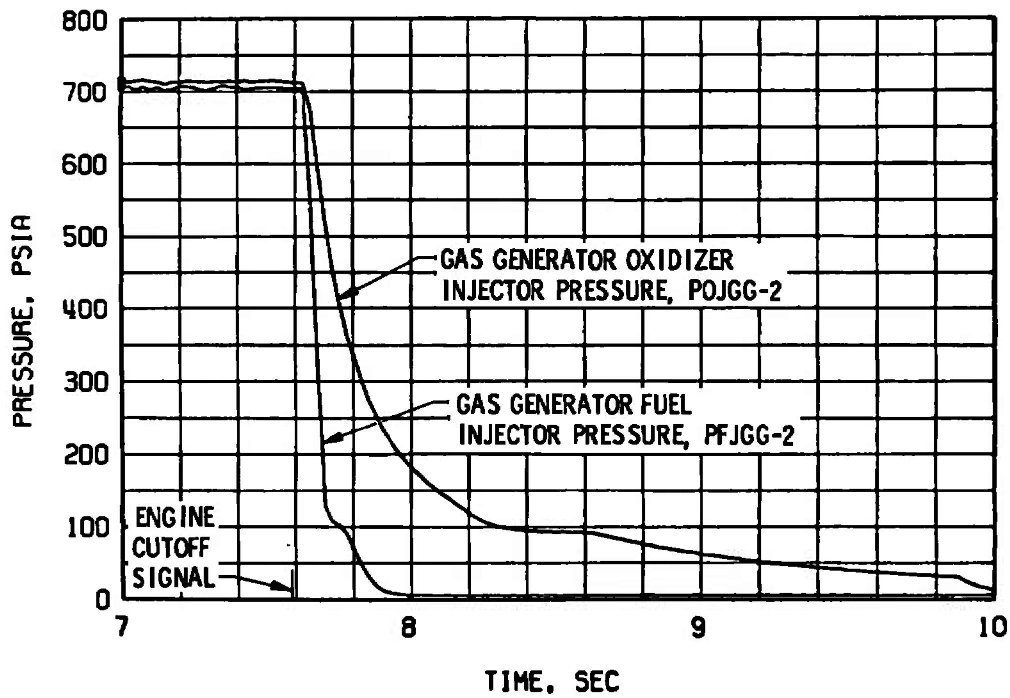


e. Thrust Chamber Fuel System, Shutdown

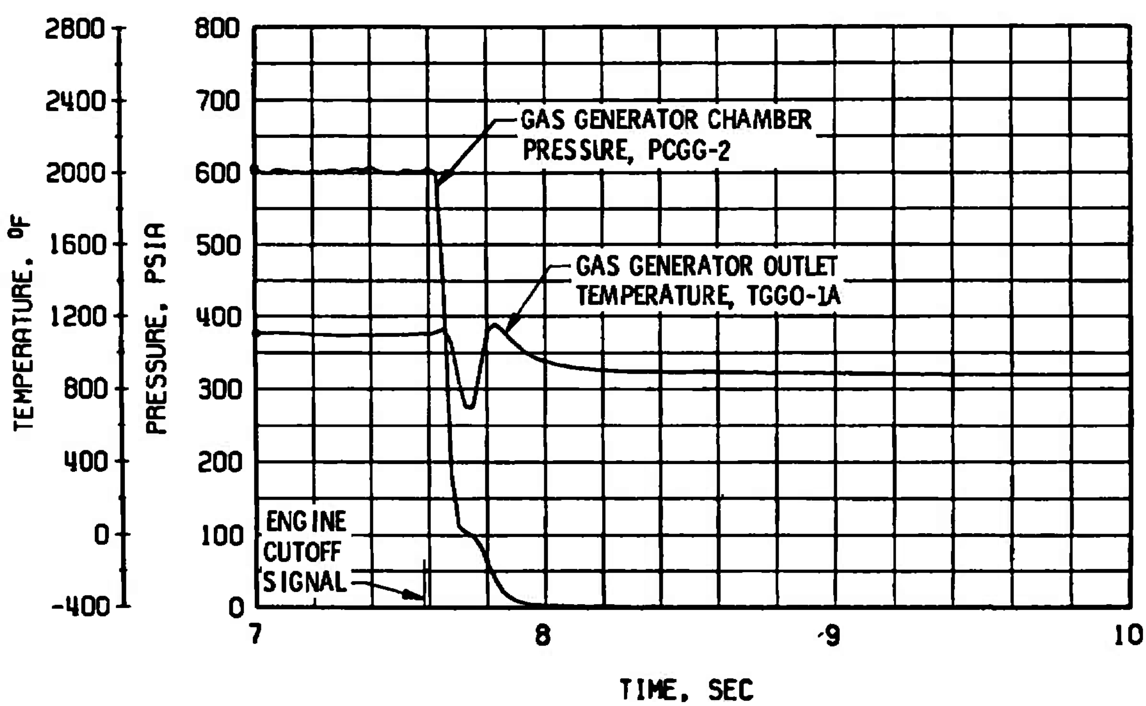


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 132 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 132 Concluded

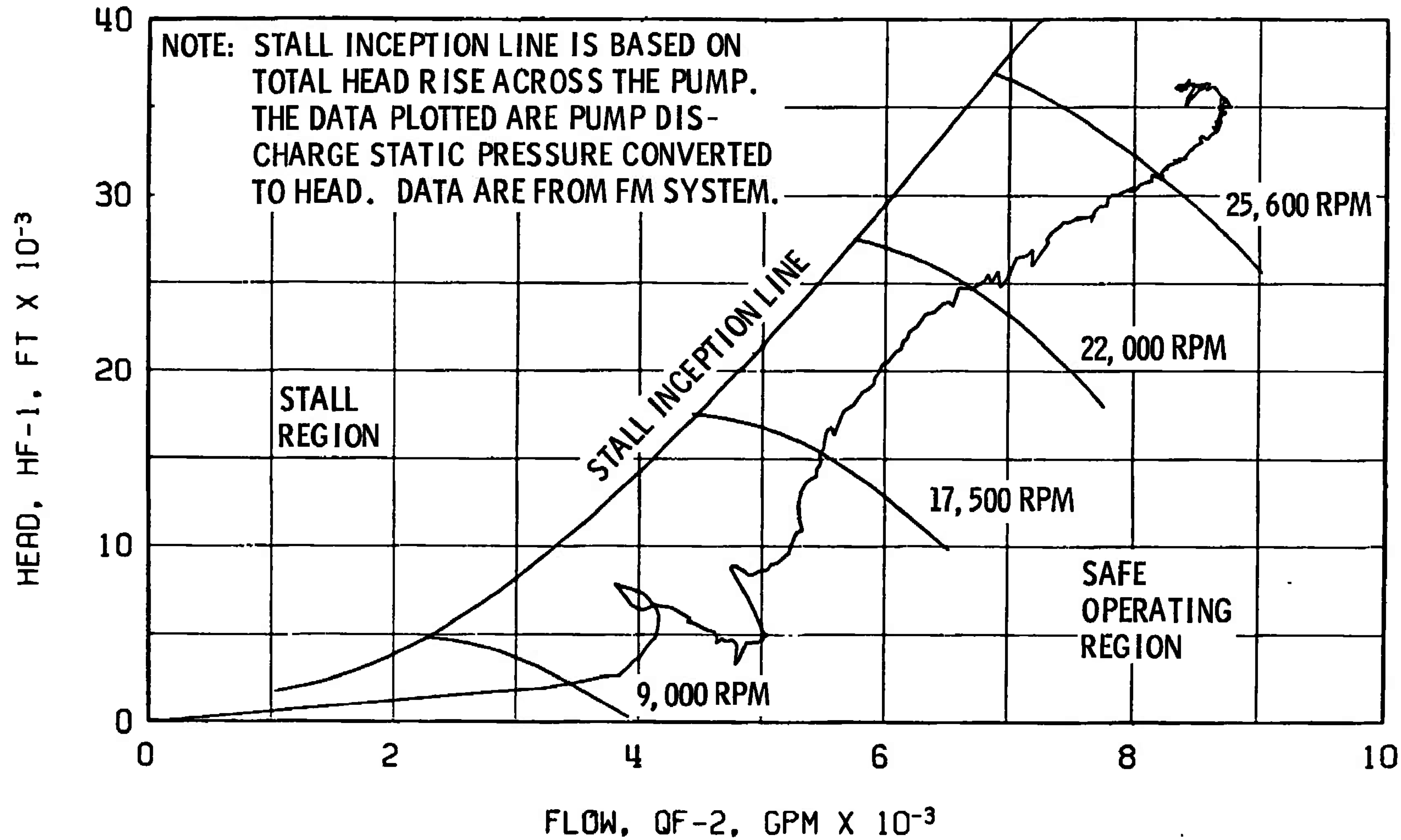
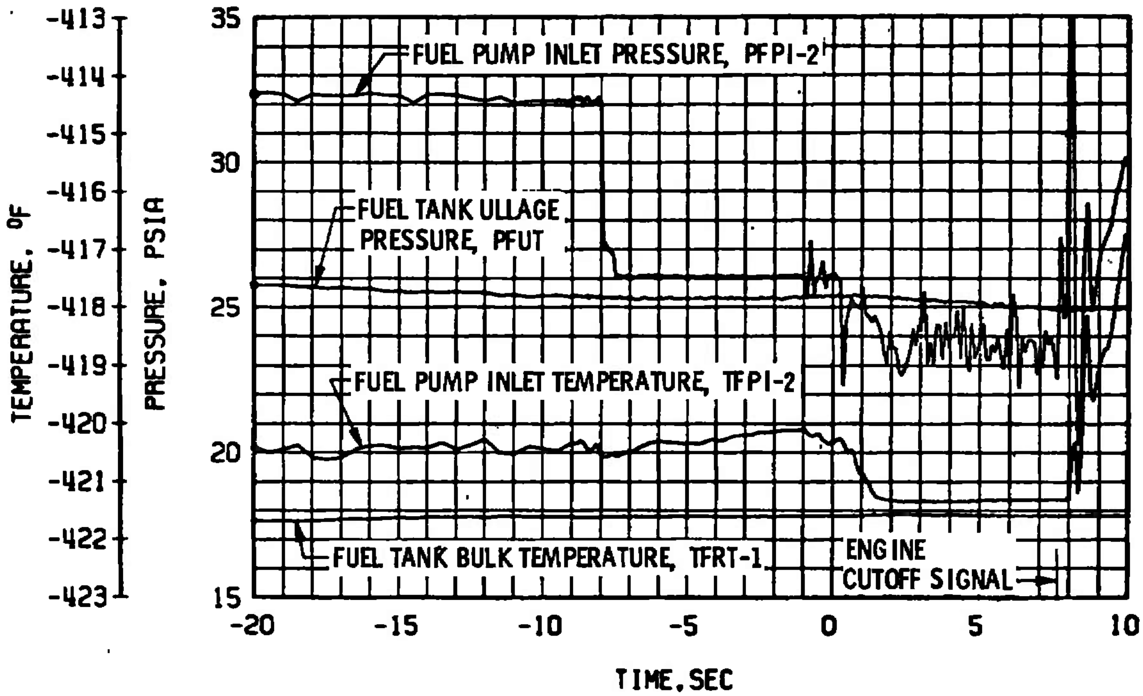
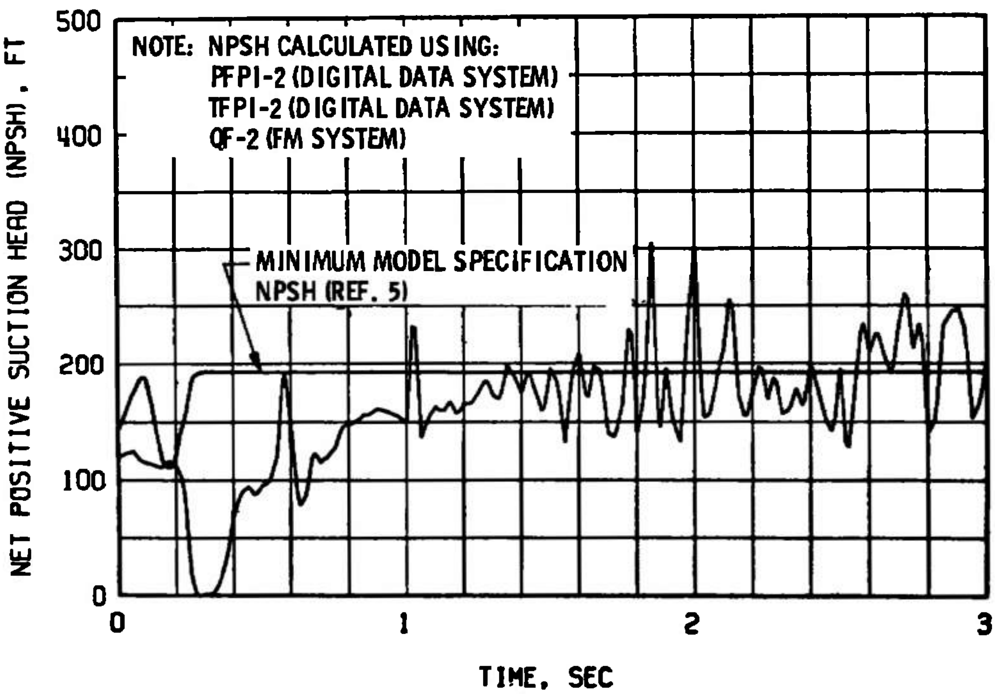


Fig. 133 Fuel Pump Start Transient Performance, Firing 33E

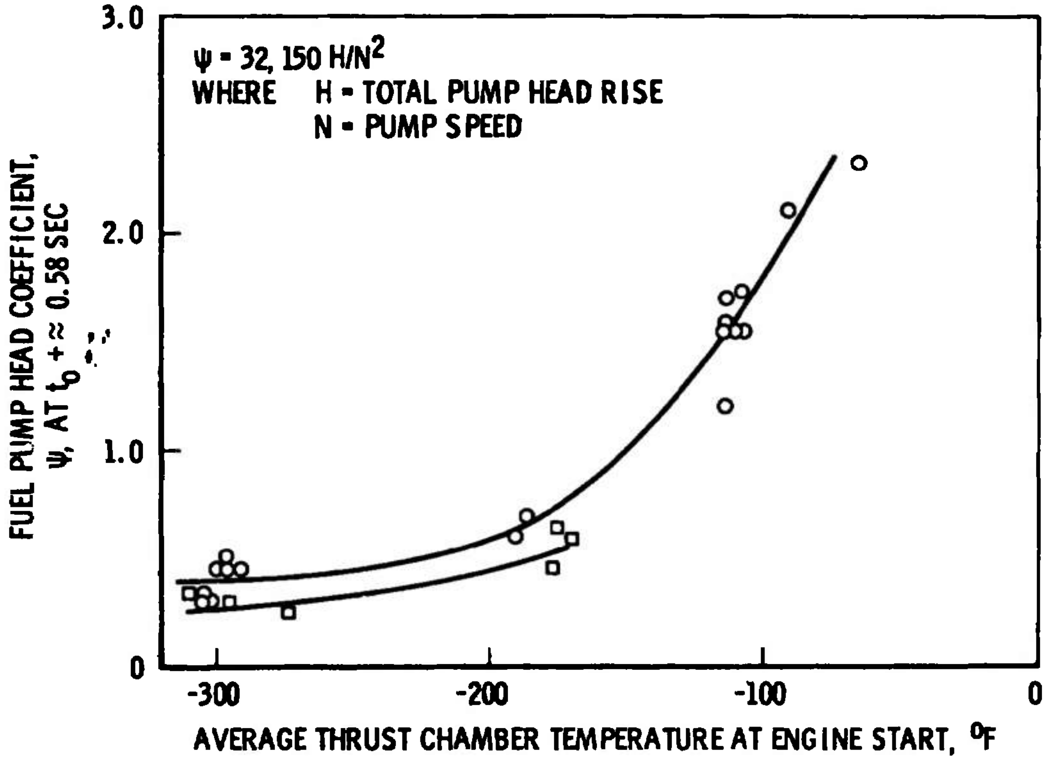


a. Duct Pressure and Temperature Transients

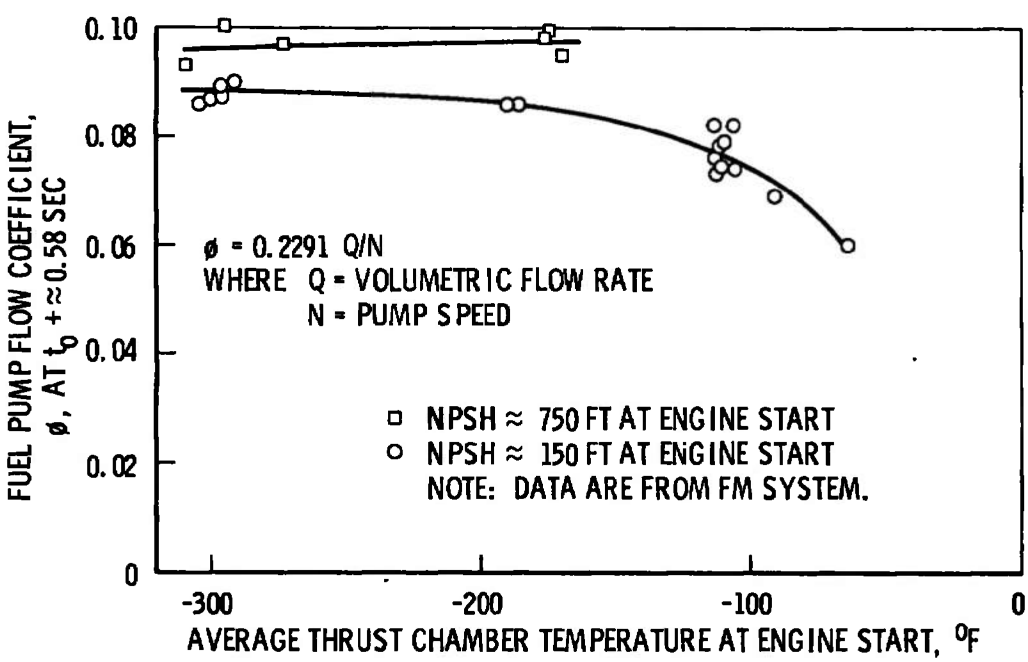


b. Fuel Pump NPSH during Start Transient, Firing 33E

Fig. 134 Fuel Low Pressure Duct Performance, Firing 33E



a. Thrust Chamber Temperature Effect on Fuel Pump Head Coefficient



b. Thrust Chamber Temperature Effect on Fuel Pump Flow Coefficient

Fig. 135 Thrust Chamber Temperature Effect on Fuel Pump Operating Characteristics

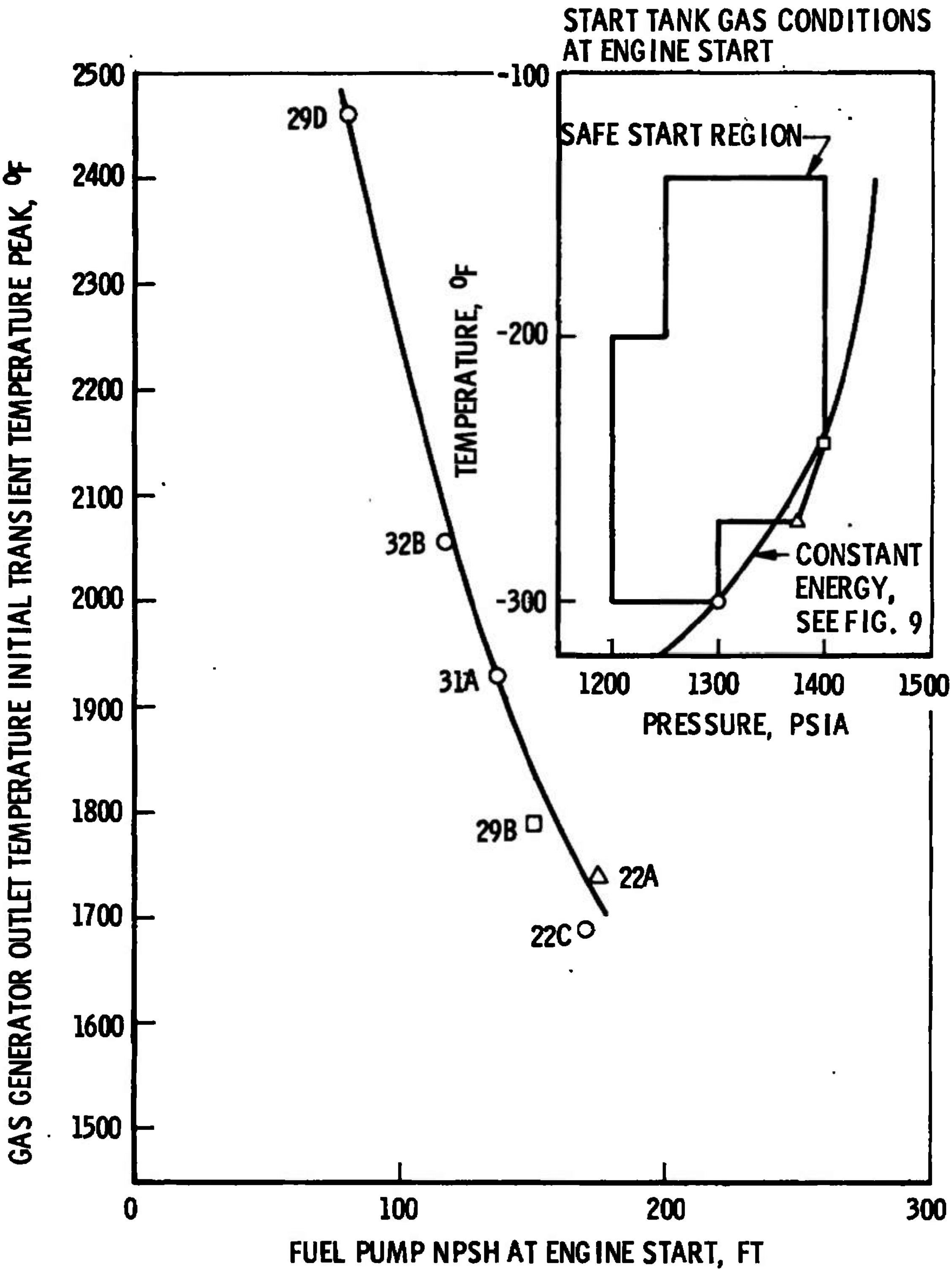


Fig. 136 Fuel Pump NPSH Effect on Gas Generator Initial Peak Temperature

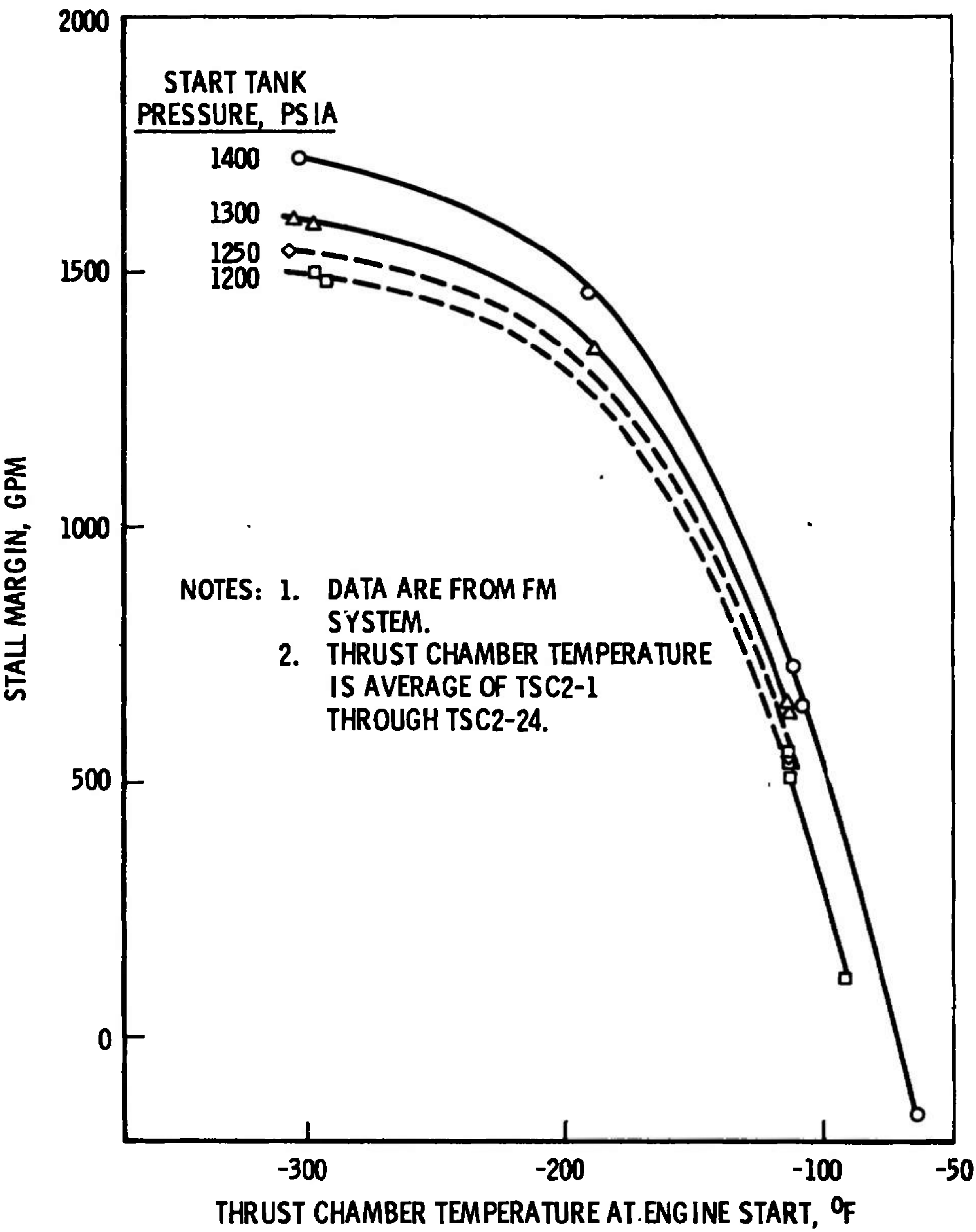


Fig. 137 Thrust Chamber Temperature Effect on Fuel Pump Stall Margin during Start Tank Discharge

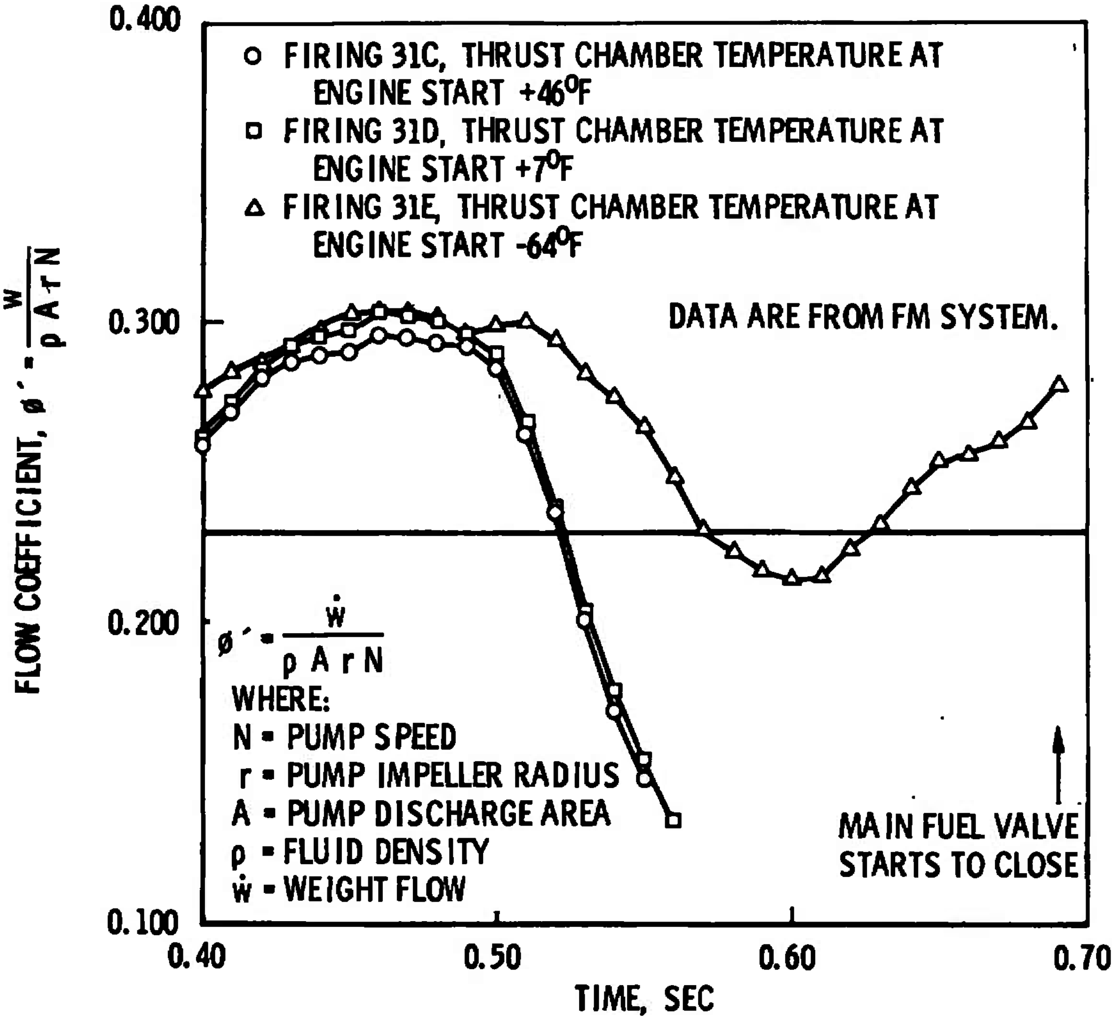


Fig. 138 Fuel Pump Start Transient Flow Coefficient, ϕ'

TABLE I
MAJOR ENGINE COMPONENTS

Part Name	P/N	S/N
Thrust Chamber Body	206600-31	4072755
Thrust Chamber Injector Assembly	208021-11	4071421
Fuel Turbopump Assembly	460160-31	4072328
Oxidizer Turbopump Assembly	458175-81	6645876
Start Tank	303435	0038
Augmented Spark Igniter	206280-81	4078806
Gas Generator Fuel Injector and Combustor	308360-11	4068543
Gas Generator Oxidizer Injector and Poppet Assembly	303323	4091740
Helium Regulator Assembly	556048	4072708
Electrical Control Package	502670-51	4087776
Primary Flight Instrumentation Package	703665	4077301
Auxiliary Flight Instrumentation Package	703680	4077313
Main Fuel Valve (Tests 28 and 29)	409120	4062172
(Test 30)	409920X6	4062093
(Tests 31, 32, and 33)	409120	4051082
Main Oxidizer Valve	411031	4085563
Gas Generator Control Valve (Tests 28, 29, 30, and 31)	309040	4074150
(Tests 32 and 33)	309040-31	4082106
Start Tank Discharge Valve	306875	4081218
Oxidizer Turbine Bypass Valve (Tests 28, 29, 30, and 31)	409930	4081242
(Tests 32 and 33)	409940	4062266
Propellant Utilization Valve	251351-11	4076732
Main-Stage Control Valve (Four-Way)	555767	8284307
Ignition Phase Control Valve (Four-Way)	555737	8284305
Helium Control Valve (Three-Way)	NA5-27273	340918
Start Tank Vent and Relief Valve	557648	4092981
Helium Tank Vent Valve	NA5-27273	340918
Fuel Bleed Valve	309034	4077233
Oxidizer Bleed Valve	309029	4076750
Augmented Spark Igniter Oxidizer Valve	308880	4085945
Pressure Actuated Shutdown Valve Assembly (Tests 29, 30, and 31)	557817	4067200
(Tests 32 and 33)	556127-11	4087661
Pressure Actuated Purge Control Valve	558126	4089662
Start Tank Fill/Refill Valve	558000	4072895
Fuel Flowmeter	251225	4076564
Oxidizer Flowmeter	251216	4077137
Fuel Injector Temperature Transducer	NA5-27441	12350
Restartable Ignition Detect Probe	NA5-27298T2	102

TABLE II
SUMMARY OF ENGINE ORIFICES

Orifice Name	Part Number	Diameter	Date Effective	Comments
Gas Generator Fuel Supply Line	RD251-4107	0.489 in.	December 28, 1967	
Gas Generator Oxidizer Supply Line	RD251-4106	0.276 in.	December 28, 1967	
Oxidizer Turbine Bypass Valve Nozzle	RD273-8002	1.430 in.	November 17, 1967	
Main Oxidizer Valve Closing Control	410437-084	8.42 scfm	January 11, 1968	Thermostatic Orifice
	410437-075	7.52 scfm	February 12, 1968	
	XEOR 920651-7	8.30 scfm	February 28, 1968	
	410437-075	7.52 scfm	March 11, 1968	
Oxidizer Turbine Exhaust Manifold	RD251-9004	10.0 in.	Installed before AEDC Delivery	
Augmented Spark Igniter Oxidizer Supply Line	406361-3	0.125 in.	February 8, 1968	

TABLE III
ENGINE MODIFICATIONS
(BETWEEN TESTS J4-1801-28 AND J4-1801-33)

Modification Number	Completion Date	Description of Modification
Test J4-1801-28, February 15, 1968		
RFD[1] March 1, 1968	February 8, 1968	0.037-in.-diam Augmented Spark Igniter Orifice Installed
RFD 69-1-67	February 8, 1968	Antiflood Valve Returned to Original Configuration
RFD 85-67	February 12, 1968	Main Oxidizer Valve Retimed to 1900^{+20}_{-10} msec
ECP[2] J2-470R1	February 9, 1968	Pressure Actuated Purge Control Valve Replaced, P/N 558126, S/N 4089662
Test J4-1801-29, February 22, 1968		
ECP J2-605	February 20, 1968	Fuel Inlet Duct Vent Port Check Valve and Bleed Plug Replaced
ECP J2-607R2	February 21, 1968	Application of Cold Test to Vent Port Check Valve
Test J4-1801-30, March 1, 1968		
RFD 9-68	February 27, 1968	Installation of a Dual Gas Generator Outlet Temperature System Redundant: P/N NA5-27342T4 S/N 615
RFD 8-68	February 23, 1968	Replacement of Main Fuel Valve P/N 409920X6, S/N 4062093
RFD 1-68	February 28, 1968	Retime Main Oxidizer Valve to 1700 msec
Test J4-1801-31, March 8, 1968		
RFD 10-68	March 5, 1968	Installation of the Gas Generator Control Valve Conditioning System
RFD 11-68	March 5, 1968	Addition of Thermocouples to the Main Fuel Valve
Test J4-1801-32, March 14, 1968		
RFD 85-67	March 12, 1968	Main Oxidizer Valve Retimed to 1750 msec
RFD 44A-67	March 11, 1968	Gas Generator Oxidizer Bootstrap Line Conditioning System Removed
RFD 17-68	March 10, 1968	Oxidizer Turbine Bypass Valve Replacement
RFD 18-68	March 10, 1968	Fast Shutdown Valve Replacement
Test J4-1801-33, March 20, 1968		

[1]Rocketdyne Field Directive

[2]Engineering Change Proposal

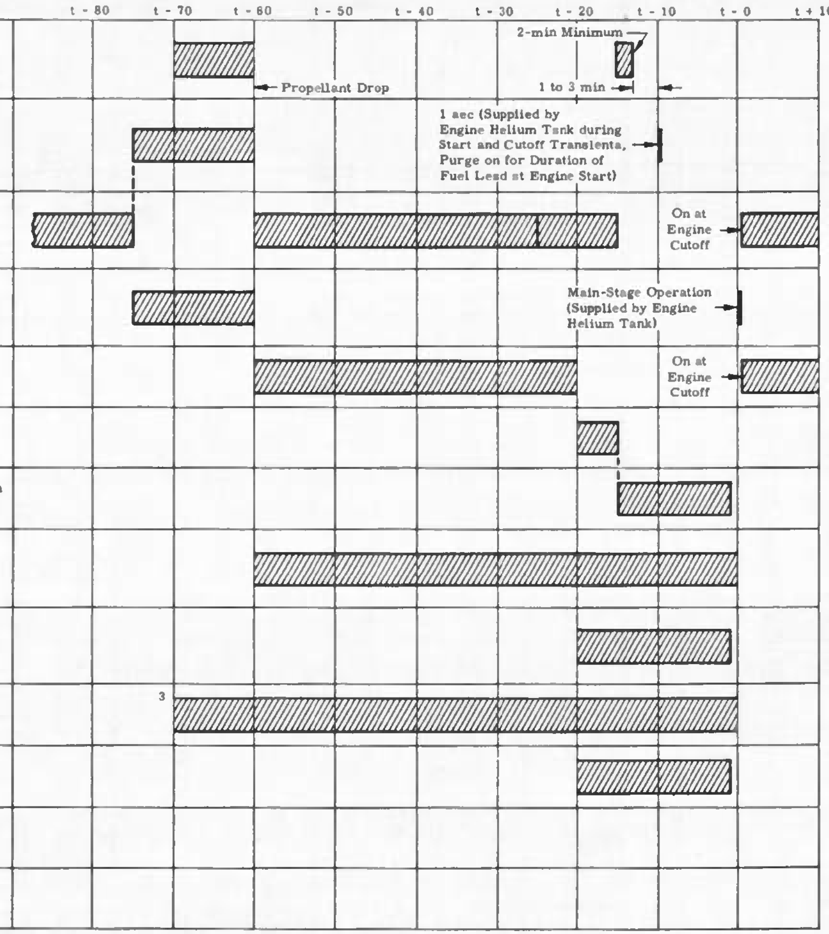
TABLE IV
ENGINE COMPONENT REPLACEMENTS
(BETWEEN TESTS J4-1801-28 AND J4-1801-33)

Replacement	Completion Date	Component Replaced
Test J4-1801-28, February 15, 1968		
None		
Test J4-1801-29, February 22, 1968		
None		
Test J4-1801-30, March 1, 1968		
None		
Test J4-1801-31, March 8, 1968		
UCR[1] 007370	March 1, 1968	Main Fuel Valve
Test J4-1801-32, March 14, 1968		
UCR 007373	March 10, 1968	Gas Generator Control Valve
Test J4-1801-33, March 20, 1968		

[1]Unsatisfactory Condition Report

TABLE V
ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE

Turbopump and Gas Generator Purge (Purge Manifold System)	Helium; 82 - 130 psia, 50 - 200°F (Nominal 6 acfm at Customer Connect
Oxidizer Dome and Gas Generator Liquid Oxygen Injector (Engine Pneumatic System)	Helium; 1400 psig, 50 - 100°F (Nominal 230 acfm at Customer Connect)
Oxidizer Dome (Facility Line to Port CO3A)	Nitrogen; 415 - 675 psia, 100 - 200°F, 175 - 230 scfm
Oxidizer Turbopump Intermediate Seal Cavity (Engine Pneumatic System)	Helium; 1400 psig, 50 - 200°F, 2600 - 7000 scfm
Thrust Chamber Jacket (Customer Connect Panel)	Nitrogen; 165 - 215 psia, 100 - 200°F, Nominal 100 scfm
	Helium; 55 - 200 psia, Ambient Temperature
Thrust Chamber Temperature Conditioning	Helium; 1000-psia Maximum, Temperature as Required
Pump Inlet Pressure and Temperature Conditioning	Oxidizer; 35 to 48 psia, -298 to 280°F; Fuel; 28 to 46 psia, -424 to 416°F
Hydrogen Start Tank and Helium Tank Pressure and Temperature Conditioning	Hydrogen; 1200 - 1400 psia, -140 to -300°F; Helium; 1700 - 3250 psia, -140 to 300°F
Crossover Duct Temperature	Helium; -300°F to Ambient
Start Tank Discharge Valve Temperature Conditioning	Helium; Ambient
Gas Generator[1] Control Valve Temperature	Helium; Ambient
Main Oxidizer[2] Valve Temperature	Oxidizer; -298 to -280°F



[1]Required on Tests 31 and 32 Only

[2]Ambient Helium to be Used if Necessary to Achieve Required Target

[3]Conditioning Temperature to be Maintained for the Last 30 min of Pre-Fire

TABLE VI
SUMMARY OF TEST REQUIREMENTS AND RESULTS

Firing Number: J4-1801-	28A Target	28A Actual	28B Target	28B Actual	28C Target	28C Actual	26A (6) Target	26A (6) Actual	26B (6) Target	26B (6) Actual	29C (6) Target	29C (6) Actual	29D (6) Target	29D (6) Actual	26E (6) Target	26E (6) Actual	00A (6)(8) Target	00A (6)(8) Actual
Time of Day, hr/Firing Date	1900	2/15/60	1922	2/15/68	2080	2/15/68	1418	2/22/68	1526	2/22/68	1621	2/22/68	1706	2/22/68	1656	2/22/68	1925	3/1/68
Pressure Altitude at Engine Start, ft (Ref. 1)	(4)	67,000	(4)	68,500	(4)	61,000	[illegible]	54,000	(4)	51,500	(4)	53,500	(4)	50,000	(4)	51,500	100,000	101,000
Firing Duration, sec (1)	(5)	0	(5)	0	0.550	0.552	7.500	7.588	7.500	7.566	7.500	7.566	7.500	1.070	7.500	7.566	7.500	7.567
Fuel Pump Inlet Conditions at Engine Start – Pressure, psia	40.0 ± 1.0	36.4	40.0 ± 1.0	36.4	40.0 ± 1.0	38.0	40.0 ± 1.0	36.6	28.0 ± 0.5	28.1	26.0 ± 0.6	25.8	26.0 ± 0.5	25.7	26.0 ± 0.5	25.6	29.6 ± 0.5	26.4
Fuel Pump Inlet Conditions at Engine Start – Temperature, °F	-422.0 ± 0.4	-421.6	-422.0 ± 0.4	-421.6	-422.0 ± 0.4	-421.3	-422.0 ± 0.4	-422.0	-420.4 ± 0.4	-420.7	-420.4 ± 0.4	-420.5	-420.0 ± 0.4	-420.2	-420.0 ± 0.4	-420.6	-420.4 ± 0.4	-420.3
Oxidizer Pump Inlet Conditions at Engine Start – Pressure, psia	30.0 ± 1.0 (6)	26.2	30.0 ± 1.0 (6)	28.7	38.0 ± 1.0	38.0	38.0 ± 1.0	36.0	45.0 ± 1.0	45.3	45.0 ± 1.0	44.7	45.0 ± 1.0	44.2	45.0 ± 1.0	44.1	$33.0^{+1.5}_{-0.0}$	34.0
Oxidizer Pump Inlet Conditions at Engine Start – Temperature, °F	---	---	---	---	-294.5 ± 0.4	-293.5	-294.5 ± 0.4	-294.1	-294.5 ± 0.4	-293.6	-294.5 ± 0.4	-294.0	-294.5 ± 0.4	-294.1	-294.5 ± 0.4	-294.3	-294.5 ± 0.4	-294.7
Start Tank Conditions at Engine Start – Pressure, psia	---	---	---	---	1400 ± 10	1361	1400 ± 10	1412	1400 ± 10	1420	1400 ± 10	1420	1300 ± 10	1323	1300 ± 10	1334	1350 ± 10	1257
Start Tank Conditions at Engine Start – Temperature, °F	---	---	---	---	-240 ± 10	-247	-240 ± 10	-245	-240 ± 10	-236	-240 ± 10	-241	-200 ± 10	-266	-300 ± 10	-200	-140 ± 10	-130
Helium Tank Conditions at Engine Start – Pressure, psia	---	1982	---	2103	---	2276	---	2278	---	2204	---	2163	---	2146	---	2274	---	2325
Helium Tank Conditions at Engine Start – Temperature, °F	---	+59	---	+53	---	-248	---	-345	---	-236	---	-241	---	-266	---	-288	---	-143
Thrust Chamber Temperature Conditions at Engine Start/t_0, °F – Throat	-250 ± 25	-266 / -306	-250 ± 25	-263 / -304	-250 ± 25	-259 / -300	-250 ± 25	-255 / -255	-275 ± 25	-284 / -384	-100 ± 25	-161 / -161	-275 ± 25	-283 / -283	-150 ± 25	-174 / -174	-275 ± 25	-291 / -291
Thrust Chamber Temperature Conditions at Engine Start/t_0, °F – Average	---	-271 / -369	---	-256 / -371	---	-295 / -365	---	-273 / -268	---	-302 / -314	---	-190 / -203	---	-304 / -318	---	-187 / -200	---	-305 / -314
Crossover Duct Temperature at Engine Start, °F (2) – TFTD-2	---	20	---	-6	+00 ± 50	13	+60 ± 50	17	+60 ± 00	44	+50 ± 50	11	+50 ± 60	17	+50 ± 50	11	-100 ± 20	-162
Crossover Duct Temperature at Engine Start, °F (2) – TFTD-2	---	68	---	45		37		39		39		35		28		36		-103
Crossover Duct Temperature at Engine Start, °F (2) – TFTD-6	---	53	---	50		20		22		34		30		29		22		-101
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F (2)	---	76	---	66	---	-123	-100 ± 50	-164	-150 ± 20	-158	-150 ± 50	-156	-150 ± 50	-166	-150 ± 50	-153	-100 ± 50	-144
Fuel Lead Time, sec (1)	8.000	7.903	8.000	7.805	8.000	7.604	1.000	1.003	1.000	1.004	1.000	1.001	1.000	1.004	1.000	1.003	1.000	1.000
Propellant in Engine Time, min	30	87	30	22	30	61	45	139	30	62	30	65	30	45	30	111	30	165
Propellant Recirculation Time, min	10	10	16	10	10	11	10	34	10	10	10	10	10	10	10	10	10	10
Start Sequence Logic	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F – TOBS-1 (10)	---	53	---	41	---	10	---	-4	---	-23	---	-101	---	-120	---	-86	---	-21
Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F – TOBS-2A	---	65	---	53	---	6	---	-14	---	-14	---	-12	---	-17	---	-14	---	23
Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F – TOBS-4	---	63	---	61	---	-63	---	-61	---	-60	---	-76	---	-76	---	-78	---	-44
Gas Generator Control Valve Body Temperature at Engine Start, °F	---	---	---	---	---	---	---	-24	---	-43	---	-183	---	-166	---	-128	---	-71
Start Tank Discharge Valve Body Temperature at Engine Start, °F	---	43	---	40	---	-32	50 ± 50	19	50 ± 50	26	50 ± 50	28	50 ± 50	21	50 ± 60	29	20 ± 25	28
Vibration Safety Counts Duration, msec and Occurrence Time, sec from t_0	--- / ---	0 / ---	--- / ---	0 / ---	--- / ---	0 / ---	--- / ---	38 / 0.066	--- / ---	20 / 1.002	--- / ---	76 / 0.008	--- / ---	156 / 1.018	--- / ---	7 / 0.803	--- / ---	38 / 1.068
Gas Generator Outlet Temperature, °F – Initial Peak	---	---	---	---	---	---	---	1676	---	1764	---	1616	---	2461	---	1665	---	1308
Gas Generator Outlet Temperature, °F – Second Peak	---	---	---	---	---	---	---	1520	---	1524	---	1445	---	---	---	1668	---	---
Thrust Chamber Ignition (P_c = 100 psia) Time, sec (Ref. t_0) (1)	---	---	---	---	---	---	---	0.966	---	1.000	---	1.000	---	1.011	---	0.965	---	1.065
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0) (1)	---	---	---	---	---	---	---	1.122	---	1.023	---	1.030	---	---	---	1.165	---	1.000
Main-Stage Pressure No. 2, sec (Ref. t_0) (1)	---	---	---	---	---	---	---	1.576	---	1.675	---	1.644	---	---	---	1.652	---	1.654
Time Chamber Pressure Attains 550 psia, sec (Ref. t_0) (1)	---	---	---	---	---	---	---	1.657	---	1.679	---	1.667	---	---	---	1.676	---	2.162
Propellant Utilization Valve Position, Engine Start/t_0 + 10 sec	--- / ---	--- / ---	--- / ---	--- / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---

Notes:
(1) Data reduced from oscillogram.
(2) Component conditioning to be maintained within limits for last 15 min before engine start.
(3) Component conditioning to be maintained within limits for last 30 min before engine start or coast duration, whichever is longer.
(4) Steam system inoperative for this test
(5) Fuel lead tests only.
(6) Helium used instead of liquid oxygen.
(7) Stall approach monitor activated.
(8) Turbine overspeed trip activated
(9) Power not supplied to propellant utilization panel.
(10) Monitored as gas generator control valve body temperature during test 02.
(11) Gas generator overtemperature cutoff.
(12) Gas generator fuel poppet leak prevented desired conditioning
(13) Terminated by the stall approach monitor

TABLE VI (Continued)

Firing Number: J4-1801-		31A (7) Target	31A Actual	31B (2)(4) Target	31B Actual	31C (5) Target	31C Actual	31D (5) Target	31D Actual
Time of Day, hr/Firing Date		1243	3/8/68	1415	3/5/68	1640	3/8/68	1710	3/6/68
Pressure Altitude at Engine Start, ft (Ref. 1)		100,000	93,500	100,000	102,000	100,000	105,000	100,000	103,000
Firing Duration, sec (1)		32.300	32.874	32.300	32.572	0.800	0.816	0.800	0.612
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	26.8 ± 0.8	26.8	26.8 ± 0.8	25.0	20.8 ± 0.8	26.7	26.5 ± 0.8	26.8
	Temperature, °F	-420.4 ± 0.4	-420.4	-420.4 ± 0.4	-426.5	-420.4 ± 0.8	-420.0	-420.4 ± 0.4	-418.8
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	45.0 ± 1.0	48.2	33.0 +1.0 -0.0	32.8	45.0 ± 1.0	44.6	45.0 ± 1.0	45.0
	Temperature, °F	-294.8 ± 0.4	-294.0	-294.8 ± 0.4	-294.3	-294.8 ± 0.4	-294.3	-294.8 ± 0.4	-294.4
Start Tank Conditions at Engine Start	Pressure, psia	1200 ± 10	1307	1200 ± 10	1204	1400 ± 10	1405	1400 ± 10	1405
	Temperature, °F	-300 ± 10	-298	-200 ± 10	-198	-240 ± 10	-240	-240 ± 10	-240
Helium Tank Conditions at Engine Start	Pressure, psia	---	2076	---	2200	---	2155	---	2077
	Temperature, °F	---	-257	---	-199	---	-220	---	-238
Thrust Chamber Temperature Conditions at Engine Start/t_0, °F	Throat	-275 ± 25	-284 / -284	-275 ± 25	-281 / -281	+50 ± 25	+44 / +43	0 ± 35	-11 / -11
	Average	---	-298 / -309	---	-201 / -204	---	+48 / +38	---	+7 / -3
Crossover Duct Temperature at Engine Start, °F (2)	TFTD-2	+60 ± 30	29	-100 ± 20	-123	+60 ± 50	-21 (11)	+60 ± 50	-61 (11)
	TFTD-3		53		-100		46		14
	TFTD-6		44		-103		40		30
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F (2)		-150 ± 50	-154	-100 ± 50	-101	-150 ± 50	-119	-150 ± 50	-8
Fuel Lead Time, sec (1)		1.000	1.000	1.000	1.001	1.000	1.001	1.000	1.002
Propellant in Engine Time, min		80	147	30	61	30	64	30	16
Propellant Recirculation Time, min		10	12	10	10	10	10	10	10
Start Sequence Logic		Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F	TOBS-1 (10)	---	+16	---	-3	---	-83	---	-46
	TOBS-2A	---	7	---	13	---	7	---	-5
	TOBS-4	---	-58	---	-43	---	-52	---	-58
Gas Generator Control Valve Body Temperature at Engine Start, °F		-25 Minimum	-10	-32 Minimum	-64	-35 Minimum	-193	-35 Minimum	-153
Start Tank Discharge Valve Body Temperature at Engine Start, °F		80 ± 25	45	80 ± 25	43	80 ± 25	51	80 ± 25	47
Vibration Safety Counts Duration, msec and Occurrence Time, sec from t_0		--- / ---	144 / 0.005	--- / ---	43 / 1.042	--- / ---	0 / ---	--- / ---	0 / ---
Gas Generator Outlet Temperature, °F	Initial Peak	---	1930	---	1440	---	---	---	---
	Second Peak	---	---	---	---	---	---	---	---
Thrust Chamber Ignition (P_c = 100 psia) Time, sec (Ref. t_0) (1)		---	0.993	---	1.094	---	---	---	---
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0) (1)		---	0.988	---	1.042	---	---	---	---
Main-Stage Pressure No. 2, sec (Ref. t_0) (1)		---	1.865	---	1.849	---	---	---	---
Time Chamber Pressure Attains 550 psia, sec (Ref. t_0) (1)		---	2.004	---	2.153	---	---	---	---
Propellant Utilization Valve Position, Engine Start/t_0 + 10 sec		Null / Closed	Null / Null (9)	Null / Closed	Null / Closed	Null / ---	Null / ---	Null / ---	Null / ---

Firing Number: J4-1801-		31E (5) Target	31E Actual	32A (5) Target	32A Actual	32B (5) Target	32B Actual	32C (7)(5) Target	32C Actual
Time of Day, hr/Firing Date		1747	3/8/68	1143	3/14/68	1243	3/14/68	1333	3/14/68
Pressure Altitude at Engine Start, ft (Ref. 1)		100,000	94,300	100,000	91,500	100,000	66,000	100,000	88,000
Firing Duration, sec (1)		0.800	0.603	7.500	7.689	7.500	7.580	1.150	1.144
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	26.8 ± 0.5	26.8	30.5 + 0.0	23.9	20.0 ± 0.0	25.2	26.5 ± 0.5	39.2
	Temperature, °F	-420.4 ± 0.4	-418.6	-420.4 ± 0.4	-430.1	-420.4 ± 0.4	-420.4	-420.4 ± 0.4	-420.2
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	45.0 ± 1.0	43.0	45.0 ± 1.0	45.8	45.0 ± 1.0	44.9	45.0 ± 1.0	44.6
	Temperature, °F	-294.8 ± 0.4	-294.2	-294.5 ± 0.4	-294.6	-294.3 ± 0.4	-294.8	-294.8 ± 0.8	-294.8
Start Tank Conditions at Engine Start	Pressure, psia	1400 ± 10	1390	1200 ± 10	1209	1300 ± 10	1307	1400 ± 10	1400
	Temperature, °F	-240 ± 10	-238	-300 ± 10	-300	-300 ± 10	-298	-340 ± 10	-342
Helium Tank Conditions at Engine Start	Pressure, psia	---	2172	---	2185	---	2206	---	2208
	Temperature, °F	---	-230	---	-303	---	-296	---	-344
Thrust Chamber Temperature Conditions at Engine Start/t_0, °F	Throat	-60 ± 25	-67 / -57	-270 ± 25	-280 / -280	-273 ± 23	-275 / -275	-75 ± 10	-75 / -76
	Average	---	-84 / -75	---	-290 / -310	---	-300 / -312	---	-107 / -110
Crossover Duct Temperature at Engine Start, °F (2)	TFTD-2	+60 ± 50	-42 (11)	+30 ± 50	43	+50 ± 60	0	+60 ± 30	40
	TFTD-3		32		32		40		49
	TFTD-6		32		44		26		42
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F (2)		-150 ± 50	-136	-150 ± 50	-130	-150 ± 50	-118	-150 ± 50	-110
Fuel Lead Time, sec (1)		1.000	1.001	1.000	1.000	1.000	1.001	1.000	1.006
Propellant in Engine Time, min		30	35	30	98	30	80	30	60
Propellant Recirculation Time, min		10	11	10	20	10	10	10	12
Start Sequence Logic		Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F	TOBS-1 (10)	---	-42	-25 Minimum	+2 (12)	-25 Minimum	10 (12)	-25 Minimum	22 (12)
	TOBS-2A	---	-9	---	-8	---	7	---	6
	TOBS-4	---	-71	---	-54	---	-46	---	-47
Gas Generator Control Valve Body Temperature at Engine Start, °F		-35 Minimum	-143	---	+31	---	-16	---	24
Start Tank Discharge Valve Body Temperature at Engine Start, °F		+80 ± 25	57	+50 ± 25	32	80 ± 30	34	80 ± 25	30
Vibration Safety Counts Duration, msec and Occurrence Time, sec from t_0		--- / ---	0 / ---	--- / ---	135 / 1.016	--- / ---	121 / 1.030	--- / ---	0 / ---
Gas Generator Outlet Temperature, °F	Initial Peak	---	---	---	1960	---	2000	---	1350
	Second Peak	---	---	---	---	---	---	---	1735
Thrust Chamber Ignition (P_c = 100 psia) Time, sec (Ref. t_0) (1)		---	---	---	1.012	---	1.003	---	0.670
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0) (1)		---	---	---	1.518	---	1.030	---	---
Main-Stage Pressure No. 2, sec (Ref. t_0) (1)		---	---	---	---	---	---	---	---
Time Chamber Pressure Attains 550 psia, sec (Ref. t_0) (1)		---	---	---	2.031	---	2.008	---	---
Propellant Utilization Valve Position, Engine Start/t_0 + 10 sec		Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---

Notes: (1) Data reduced from oscillogram.
(2) Component conditioning to be maintained within limits for last 15 min before engine start.
(3) Component conditioning to be maintained within limits for last 30 min before engine start or coast duration, whichever is longer.
(4) Steam system inoperative for this test.
(5) Fuel lead tests only.
(6) Helium used instead of liquid oxygen.
(7) Stall approach monitor activated.
(8) Turbine overspeed trip activated.
(9) Power not supplied to propellant utilization panel.
(10) Monitored as gas generator control valve body temperature during test 32.
(11) Gas generator overtemperature cutoff.
(12) Gas generator fuel poppet leak prevented desired conditioning.
(13) Terminated by the stall approach monitor.

TABLE VI (Concluded)

Firing Number: J4-1801-		53D⑦⑧		22E⑦⑧		52F⑦⑧		52G⑦⑧		23A⑦⑧		55B⑦⑧		33C⑦⑧		23D⑦⑧		53E⑦⑧	
		Target	Actual	Target	Actual	Target	Actual	Target	Actual	Target	Actual	Target	Actual	Target	Actual	Target	Actual	Target	Actual
Time of Day, hr/Firing Date		1453	3/14/68	1604	3/14/68	1655	3/14/68	1730	3/14/68	1313	3/30/68	1440	3/20/68	1550	3/20/68	1641	3/20/68	1734	3/20/68
Pressure Altitude at Engine Start, ft (Ref. 1)		100,000	100,000	100,000	100,000	100,000	108,500	100,000	108,500	100,000	98,000	100,000	113,000	100,000	111,000	100,000	116,000	100,000	113,000
Firing Duration, sec①		1.150	0.86⑪	1.150	1.138	1.150	1.130	1.150	1.137	38.500	32.57	7.500	7.50	7.500	7.52	7.500	7.59	7.500	7.59
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	29.5 ± 0.5	30.0	28.5 ± 0.5	29.8	25.5 ± 0.5	30.0	26.5 ± 0.5	25.7	30.8 ± 0.5	30.8	25.5 ± 0.5	26.0	26.6 ± 0.5	25.8	29.8 ± 0.5	36.8	28.8 ± 0.5	36.0
	Temperature, °F	-420.4 ± 0.4	-420.5	-420.4 ± 0.4	-420.4	-420.4 ± 0.4	-420.0	-420.4 ± 0.4	-420.2	-420.4 ± 0.4	-430.1	-420.4 ± 0.4	-420.5	-420.4 ± 0.4	-420.5	-420.4 ± 0.4	-420.4	-420.4 ± 0.4	-420.2
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	45.0 ± 1.0	45.1	45.0 ± 1.0	44.4	45.0 ± 1.0	45.0	45.0 ± 1.0	45.4	45.0 ± 1.0	45.7	45.0 ± 1.0	45.5	45.0 ± 1.0	44.3	45.0 ± 1.0	44.7	45.0 ± 1.0	46.5
	Temperature, °F	-294.5 ± 0.4	-294.2	-294.5 ± 0.4	-295.2	-294.5 ± 0.4	-294.5	-294.5 ± 0.4	-294.4	-294.5 ± 0.4	-294.0	-294.5 ± 0.4	-294.7	-294.5 ± 0.4	-294.9	-294.5 ± 0.4	-294.8	-294.5 ± 0.6	-294.7
Start Tank Conditions at Engine Start	Pressure, psia	1200 ± 10	1198	1200 ± 10	1203	1200 ± 10	1205	1500 ± 10	1300	1200 ± 10	1206	1300 ± 10	1305	1400 ± 10	1505	1350 ± 10	1247	1200 ± 10	1205
	Temperature, °F	-200 ± 10	-202	-200 ± 10	-199	-300 ± 10	-301	-300 ± 10	-293	-200 ± 10	-129	-300 ± 10	-302	-240 ± 10	-242	-140 ± 10	-140	-300 ± 10	-301
Helium Tank Conditions at Engine Start	Pressure, psia	---	2217	---	2262	---	2194	---	2255	---	2140	---	2148	---	2197	---	2150	---	2118
	Temperature, °F	---	-187	---	-185	---	-288	---	-282	---	-187	---	-201	---	-229	---	-140	---	-208
Thrust Chamber Temperature Conditions at Engine Start/t_0, °F	Throat	-75 ± 15	-84 / -84	-85 +0 -15	-84 / -84	-85 +0 -15	-90 / -90	-85 +0 -15	-90 / -90	-100 ± 10	-84 / -84	-100 ± 15	-85 / -85	-100 ± 15	-89 / -89	-100 ± 15	-89 / -89	-100 ± 15	-88 / -88
	Average	---	-91 / -103	---	-112 / -122	---	-110 / -122	---	-112 / -123	---	-108 / -117	---	-114 / -135	---	-111 / -122	---	-113 / -124	---	-113 / -124
Crossover Duct Temperature at Engine Start, °F④	TFTD-2	50 ± 50	29	50 ± 50	27	50 ± 50	30	50 ± 50	28	50 ± 50	52	50 ± 50	53	50 ± 50	54	50 ± 50	71	50 ± 50	84
	TFTD-3		43		55		84		51		87		84		85		79		80
	TFTD-8		29		27		37		24		84		40		52		88		69
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F③		-150 ± 50	-118	-150 ± 50	-117	-150 ± 50	-118	-150 ± 50	-118	-100 ± 50	-55	-100 ± 50	-130	-100 ± 50	-140	-100 ± 50	-146	-100 ± 50	-141
Fuel Lead Time, sec①		1.000	1.001	1.000	1.000	1.000	1.000	1.000	1.001	1.000	1.001	1.000	1.001	1.000	1.002	1.000	1.001	1.000	1.001
Propellant in Engine Time, min		30	80	30	71	30	51	30	55	30	106	30	-96	50	81	30	81	30	53
Propellant Recirculation Time, min		10	43	10	23	10	11	10	11	10	11	10	12	10	12	10	10	10	11
Start Sequence Logic		Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F	TOBS-1⑩	-25 Minimum	21⑩	-25 Minimum	30⑩	-25 Minimum	18⑩	-25 Minimum	17⑩	---	42	---	36	---	28	---	21	---	22
	TOBS-2A	---	8	---	8	---	5	---	-2	---	22	---	15	---	9	---	4	---	5
	TOBS-4	---	-48	---	-47	---	-45	---	-52	---	-28	---	-38	---	-42	---	-45	---	-44
Gas Generator Control Valve Body Temperature at Engine Start, °F		---	22	---	28	---	27	---	28	---	---	---	---	---	---	---	---	---	---
Start Tank Discharge Valve Body Temperature at Engine Start, °F		50 ± 25	30	50 ± 25	36	50 ± 25	55	50 ± 25	32	50 ± 25	52	50 ± 25	48	50 ± 25	40	50 ± 25	88	50 ± 25	40
Vibration Safety Counts Duration, msec and Occurrence Time, sec from t_0		--- / ---	0 / ---	--- / ---	0 / ---	--- / ---	0 / ---	--- / ---	0 / ---	--- / ---	0 / ---	--- / ---	0 / ---	--- / ---	0 / ---	--- / ---	0 / ---	--- / ---	0 / ---
Gas Generator Outlet Temperature, °F	Initial Peak	---	---	---	1850	---	1770	---	1840	---	1810	---	1903	---	1644	---	1725	---	1804
	Second Peak	---	---	---	---	---	1734	---	1791	---	1810	---	2036	---	2036	---	1521	---	1817
Thrust Chamber Ignition (P_c = 100 psia) Time, sec (Ref. t_0)①		---	---	---	1.007	---	0.978	---	0.985	---	1.110	---	0.993	---	0.980	---	1.030	---	0.999
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0)①		---	---	---	---	---	---	---	---	---	1.201	---	1.383	---	1.517	---	1.106	---	1.130
Main-Stage Pressure No. 3, sec (Ref. t_0)①		---	---	---	---	---	---	---	---	---	1.855	---	1.502	---	1.837	---	1.880	---	1.590
Time Chamber Pressure Attains 550 psia, sec (Ref. t_0)①		---	---	---	---	---	---	---	---	---	1.922	---	1.855	---	1.832	---	1.895	---	1.020
Propellant Utilization Valve Position, Engine Start/t_0 + 10 sec		Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / Closed	Null / Closed	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---

Notes:
① Data reduced from oscillogram.
② Component conditioning to be maintained within limits for last 15 min before engine start.
③ Component conditioning to be maintained within limits for last 30 min before engine start or coast duration, whichever is longer.
④ Steam system inoperative for this test
⑤ Fuel lead tests only.
⑥ Helium used instead of liquid oxygen.
⑦ Stall approach monitor activated.
⑧ Turbine overspeed trip activated.
⑨ Power not supplied to propellant utilization panel.
⑩ Monitored as gas generator control valve body temperature during test 22.
⑪ Gas generator overtemperature cutoff.
⑫ Gas generator fuel poppet leak prevented desired conditioning.
⑬ Terminated by the stall approach monitor.

TABLE VII
ENGINE VALVE TIMINGS
a. Start

Firing Number J4-1801-	Start																								
	Start Tank Discharge Valve						Main Fuel Valve			Main Oxidizer Valve First Stage			Main Oxidizer Valve Second Stage			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec
28A	---	---	---	---	---	---	-7.800	0.052	0.068	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
28B	---	---	---	---	---	---	-7.905	0.053	0.088	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
28C	0.0	0.156	0.148	---	---	---	-7.804	0.053	0.068	0.449	0.062	0.055	---	---	---	---	---	---	---	---	---	---	---	---
29A	0.0	0.147	0.136	0.448	0.091	0.240	-0.998	0.060	0.060	0.448	0.050	0.052	0.448	0.672	2.120	0.448	0.120	0.030	0.448	0.202	0.085	0.448	0.232	0.310
29B	0.0	0.147	0.135	0.447	0.085	0.240	-1.000	0.057	0.045	0.447	0.055	0.060	0.447	0.585	2.210	0.447	0.120	0.030	0.447	0.200	0.090	0.447	0.225	0.310
28C	0.0	0.148	0.140	0.448	0.090	0.235	-0.897	0.055	0.065	0.448	0.060	0.060	0.448	0.580	2.260	0.448	0.125	0.040	0.448	0.225	0.120	0.448	0.230	0.310
28D	0.0	0.142	0.130	0.447	0.090	0.235	-1.000	0.052	0.070	0.447	0.060	0.055	---	---	---	0.447	0.127	0.038	0.447	0.230	0.130	0.447	0.225	0.350
28E	0.0	0.140	0.130	0.448	0.090	0.230	-1.000	0.055	0.070	0.448	0.050	0.057	0.448	0.713	2.150	0.448	0.123	0.035	0.448	0.213	0.110	0.448	0.227	0.340
30A	0.0	0.141	0.128	0.450	0.089	0.241	-1.000	0.092	0.039	0.450	0.060	0.054	0.450	0.560	1.833	0.450	0.114	0.039	0.450	0.198	0.090	0.450	0.233	0.288
31A	0.0	0.145	0.130	0.450	0.090	0.230	-1.000	0.067	0.060	0.450	0.055	0.055	0.450	0.535	2.005	0.450	0.110	0.037	0.450	0.185	0.077	0.450	0.215	0.300
31B	0.0	0.133	0.126	0.448	0.089	0.240	-1.000	0.055	0.075	0.448	0.056	0.054	0.448	0.594	1.855	0.449	0.114	0.033	0.448	0.194	0.082	0.448	0.230	0.280
31C	0.0	0.145	0.132	0.450	---	---	-1.000	0.060	0.055	0.450	0.055	0.055	0.450	---	---	0.450	---	---	0.450	---	---	0.450	---	---
31D	0.0	0.144	0.134	0.448	---	---	-1.000	0.055	0.085	0.449	0.055	0.050	0.449	---	---	0.449	---	---	0.449	---	---	0.448	---	---
31E	0.0	0.147	0.135	0.450	---	---	-1.000	0.055	0.065	0.450	0.055	0.055	0.450	---	---	0.450	---	---	0.450	---	---	0.450	---	---
32A	0.0	0.138	0.127	0.448	0.091	0.236	-0.999	0.066	0.059	0.448	0.060	0.052	0.448	0.571	2.162	0.448	0.116	0.027	0.448	0.185	0.077	0.448	0.229	0.295
32B	0.0	0.140	0.128	0.450	0.080	0.234	-1.000	0.110	0.036	0.450	0.058	0.052	0.450	0.580	2.218	0.450	0.120	0.027	0.450	0.180	0.091	0.450	0.232	0.282
32C	0.0	0.146	0.134	0.450	0.082	0.224	-1.000	0.056	0.068	0.450	0.060	0.052	0.450	---	---	0.450	0.124	0.026	0.450	0.192	0.085	0.450	0.235	0.290
32D	0.0	0.137	0.129	0.448	0.092	---	-1.000	0.053	0.068	0.448	0.055	0.056	0.448	---	---	0.448	0.118	0.026	0.448	0.184	---	0.448	---	---
32E	0.0	0.137	0.124	0.447	0.092	0.240	-0.999	0.054	0.070	0.447	0.057	0.053	0.447	---	---	0.447	0.115	0.031	0.447	0.184	0.083	0.447	0.237	0.287
32F	0.0	0.136	0.125	0.446	0.093	0.238	-0.999	0.050	0.067	0.446	0.058	0.052	0.446	---	---	0.446	0.119	0.024	0.446	0.189	0.080	0.446	0.240	0.295
32G	0.0	0.140	0.130	0.448	0.003	0.238	-1.001	0.055	0.066	0.448	0.058	0.054	0.448	---	---	0.448	0.115	0.027	0.448	0.186	0.082	0.448	0.243	0.288
33A	0.0	0.140	0.124	0.450	0.093	0.236	-1.001	0.053	0.083	0.450	0.055	0.051	0.450	0.751	2.132	0.450	0.113	0.029	0.450	0.188	0.086	0.450	0.207	0.280
33B	0.0	0.140	0.130	0.448	0.090	0.238	-1.000	0.053	0.071	0.448	0.057	0.058	0.448	0.855	2.015	0.448	0.122	0.025	0.448	0.192	0.083	0.448	0.210	0.278
33C	0.0	0.144	0.134	0.447	0.089	0.236	-1.002	0.053	0.068	0.447	0.057	0.057	0.447	0.870	1.986	0.447	0.123	0.025	0.447	0.192	0.081	0.447	0.210	0.274
33D	0.0	0.137	0.125	0.445	0.081	0.236	-1.000	0.053	0.072	0.445	0.058	0.057	0.445	0.682	2.152	0.445	0.124	0.026	0.445	0.188	0.083	0.445	0.229	0.275
33E	0.0	0.136	0.125	0.446	0.088	0.235	-1.003	0.051	0.071	0.446	0.055	0.058	0.446	0.624	2.151	0.446	0.120	0.026	0.448	0.187	0.080	0.446	0.205	0.277

Notes: 1. All valve signal times are referenced to t_0.
2. Valve delay time is the time required for initial valve movement after the valve "open" or valve "closed" solenoid has been energized.
3. Data are reduced from an oscillogram.
4. Final sequence check is conducted without propellants within 12 hr before testing.

TABLE VII (Continued)
b. Shutdown

Firing Number J4-1801-	Shutdown: Main Fuel Valve: Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Main Oxidizer Valve: Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Gas Generator Fuel Poppet: Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Gas Generator Oxidizer Poppet: Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Oxidizer Turbine Bypass Valve: Time of Closing Signal	Valve Delay Time, sec	Valve Opening Time, sec
28A	---	0.080	0.300	---	---	---	---	---	---	---	---	---	---	---	---
28B	---	0.118	0.312	---	---	---	---	---	---	---	---	---	---	---	---
28C	0.652	0.095	0.343	---	---	---	---	---	---	---	---	---	---	---	---
29A	7.588	0.140	0.370	7.588	0.080	0.195	7.588	0.060	0.025	7.588	0.030	0.015	7.588	0.272	0.450
29B	7.585	0.140	0.375	7.585	0.080	0.185	7.585	0.065	0.020	7.585	0.035	0.020	7.585	0.275	0.375
28C	7.587	0.138	0.365	7.587	0.080	0.180	7.587	0.078	0.020	7.587	0.036	0.017	7.587	0.268	0.400
28D	1.074	0.118	0.320	1.074	---	---	1.074	0.083	0.030	1.074	0.045	0.023	1.074	0.118	0.460
29E	7.570	0.145	0.370	7.570	0.080	0.185	7.570	0.080	0.030	7.570	0.020	0.020	7.570	0.280	0.420
30A	7.587	0.128	0.365	7.587	0.082	0.193	7.587	0.064	0.036	7.587	0.031	0.017	7.587	0.285	0.553
31A	32.58	0.125	0.350	32.58	0.087	0.188	32.58	0.058	0.024	32.58	0.030	0.017	32.58	0.310	0.440
31B	32.58	0.123	0.350	32.58	0.080	0.188	32.58	0.068	0.030	32.58	0.030	0.018	32.58	0.343	0.485
31C	0.620	0.085	0.265	0.820	---	---	0.620	---	---	0.620	---	---	0.620	---	---
31D	0.612	0.088	0.250	0.612	---	---	0.612	---	---	0.812	---	---	0.612	---	---
31E	0.804	0.090	0.263	0.604	---	---	0.804	---	---	0.604	---	---	0.604	---	---
32A	7.583	0.117	0.348	7.583	0.075	0.188	7.583	0.073	0.021	7.593	0.031	0.028	7.583	0.218	0.457
32B	7.581	0.125	0.378	7.581	0.077	0.186	7.581	0.082	0.022	7.591	0.035	0.025	7.581	0.216	0.408
32C	1.148	0.110	0.318	1.148	---	---	1.148	0.085	0.021	1.148	0.048	0.024	1.148	0.115	0.470
32D	0.683	0.098	0.280	0.663	---	---	0.883	---	---	0.663	---	---	0.863	---	---
32E	1.138	0.110	0.307	1.138	---	---	1.138	0.084	0.024	1.138	0.047	0.028	1.138	0.117	0.475
32F	1.137	0.109	0.308	1.137	---	---	1.137	0.083	0.020	1.137	0.049	0.026	1.137	0.115	0.500
32G	1.137	0.110	0.310	1.137	---	---	1.137	0.085	0.018	1.137	0.048	0.025	1.137	0.123	0.525
33A	32.578	0.107	0.280	32.576	0.072	0.178	32.578	0.074	0.024	32.578	0.031	0.022	32.576	0.238	0.620
33B	7.582	0.115	0.340	7.682	0.075	0.183	7.582	0.081	0.020	7.592	0.034	0.024	7.682	0.246	0.510
33C	7.590	0.115	0.334	7.580	0.076	0.190	7.590	0.077	0.025	7.590	0.035	0.022	7.580	0.241	0.493
33D	7.588	0.115	0.337	7.589	0.075	0.185	7.589	0.079	0.017	7.588	0.034	0.020	7.588	0.243	0.470
33E	7.592	0.114	0.338	7.592	0.078	0.188	7.592	0.081	0.020	7.592	0.038	0.020	7.592	0.238	0.470

Notes: 1. All valve signal times are referenced to t_0.
2. Valve delay time is the time required for the initial valve movement after the valve "open" or valve "closed" solenoid has been energized.
3. Data are reduced from an oscillogram.
4. Final sequence check is conducted without propellants within 12 hr before testing.

TABLE VII (Concluded)

c. Final Sequeuce

Firing Number J4-1801-	Start																					
	Start Tank Discharge Valve						Main Fuel Valve			Main Oxidizer Valve First Stage			Main Oxidizer Valve Second Stage			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec
28	0	0.097	0.110	0.450	0.090	0.245	-1.000	0.045	0.070	0.450	0.053	0.050	0.450	0.625	1.910	0.450	0.043	0.040	0.450	0.150	0.070	0.450	0.220	0.320
29	0	0.100	0.112	0.445	0.090	0.250	-1.000	0.045	0.070	0.445	0.050	0.050	0.445	0.630	1.955	0.445	0.080	0.035	0.445	0.155	0.070	0.445	0.220	0.250
30	0	0.097	0.113	0.450	0.090	0.245	-1.000	0.045	0.065	0.450	0.050	0.047	0.450	0.570	1.750	0.450	0.080	0.042	0.450	0.150	0.067	0.450	0.200	0.350
31	0	0.100	0.110	0.450	0.095	0.240	-1.000	0.045	0.072	0.450	0.050	0.045	0.450	0.572	1.788	0.450	0.090	0.032	0.450	0.150	0.070	0.450	0.200	0.280
32	0	0.100	0.115	0.450	0.093	0.247	-1.001	0.045	0.075	0.450	0.053	0.044	0.450	0.617	1.924	0.450	0.091	0.027	0.450	0.141	0.077	0.450	0.211	0.300
33	0	0.136	0.125	0.446	0.088	0.235	-1.003	0.051	0.071	0.446	0.055	0.058	0.446	0.674	2.151	0.448	0.120	0.026	0.448	0.187	0.080	0.446	0.205	0.277

Firing Number J4-1801-	Shutdown														
	Main Fuel Valve			Main Oxidizer Valve			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec
26	---	0.088	0.130	---	0.088	0.239	---	0.052	0.052	---	0.052	0.028	---	0.212	0.570
29	---	0.087	0.237	---	0.067	0.130	---	0.082	0.025	---	0.054	0.020	---	0.150	0.550
30	---	0.083	0.243	---	0.066	0.130	---	0.060	0.030	---	0.050	0.023	---	0.233	0.560
31	---	0.085	0.237	---	0.084	0.130	---	0.077	0.028	---	0.050	0.022	---	0.233	0.580
32	---	0.083	0.243	---	0.063	0.133	---	0.103	0.032	---	0.062	0.031	---	0.207	0.523
33	---	0.083	0.237	---	0.065	0.129	---	0.104	0.029	---	0.064	0.032	---	0.228	0.567

Notes: 1. All valve signal timee are referenced to t_0.
2. Valve delay time is the time required for initial valve movement after the valve "open" or "closed" solenoid has been energized.
3. Final sequence check is conducted without propellants and within 12 hr before testing.
4. Data reduced from oscillogram.

TABLE VIII
ENGINE PERFORMANCE SUMMARY

Firing Number J4-1801-		31B		33A	
		Site	Normalized	Site	Normalized
Overall Engine Performance	Thrust, lb_f	229,621	228,406	228,923	227,566
	Chamber Pressure, psia	775	767	772	765
	Mixture Ratio	5.7	5.7	5.7	5.6
	Fuel Weight Flow, lb_m/sec	82.5	81.7	82.5	81.8
	Oxidizer Weight Flow, lb_m/sec	467.7	463.5	466.3	461.2
	Total Weight Flow, lb_m/sec	550.2	545.2	548.8	543.0
Thrust Chamber Performance	Mixture Ratio	5.9	5.9	5.9	5.9
	Total Weight Flow, lb_m/sec	543	538	542	536
	Characteristic Velocity, ft/sec	7807	7804	7804	7808
Fuel Turbopump Performance	Pump Efficiency, percent	73	73	73	73
	Pump Speed, rpm	27,071	26,889	27,204	26,975
	Turbine Efficiency, percent	60	60	62	62
	Turbine Pressure Ratio	7.2	7.2	7.1	7.1
	Turbine Inlet Temperature, °F	1267	1249	1254	1230
	Turbine Weight Flow, lb_m/sec	7.1	7.1	7.0	7.0
Oxidizer Turbopump Performance	Pump Efficiency, percent	81	80	81	80
	Pump Speed, rpm	8713	8659	8684	8630
	Turbine Efficiency, percent	49	49	49	49
	Turbine Pressure Ratio	2.7	2.7	2.6	2.6
	Turbine Inlet Temperature, °F	815	802	820	802
	Turbine Weight Flow, lb_m/sec	6.3	6.3	6.2	6.2
Gas Generator Performance	Mixture Ratio	0.98	0.97	0.97	0.96
	Chamber Pressure, psia	693	688	685	679

Notes:
1. Site data are calculated from test data.
2. Normalized data are corrected to standard pump inlet and engine ambient pressure conditions.
3. Input data are test data averaged from 29 to 30 sec, except as noted.
4. Site and normalized data were computed using the Rocketdyne PAST 640 modification zero computer program.

APPENDIX III
INSTRUMENTATION

The instrumentation for AEDC tests J4-1801-28 through -33 is tabulated in Table III-1. The location of selected major engine instrumentation is shown in Fig. III-1.

TABLE III-1
INSTRUMENTATION LIST
(FOR TESTS J4-1801-28 THROUGH 33)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Current		**amp**					
ICC	Control		0 to 30	x		x		
IIC	Ignition		0 to 30	x		x		
	Event							
EASIOV(1)	Augmented Spark Igniter Oxidizer Valve Open		On/Off	x		x		
EECL	Engine Cutoff Lockin		On/Off	x		x		
EECO	Engine Cutoff Signal		On/Off	x	x	x		
EES	Engine Start Command		On/Off	x		x		
EFBVC	Fuel Bleed Valve Closed Limit		Open/Closed	x				
EFPVC/O	Fuel Prevalve Closed/Open Limit		Closed/Open	x		x(1)		
EHCS	Helium Control Solenoid		On/Off	x		x		
EID	Ignition Detected		On/Off	x		x		
EIPCS	Ignition Phase Control Solenoid		On/Off	x		x		
EMCS	Main-Stage Control Solenoid		On/Off	x		x		
EMP-1	Main-Stage Pressure No. 1		On/Off	x		x		
EMP-2	Main-Stage Pressure No. 2		On/Off	x		x		
EOBVC	Oxidizer Bleed Valve Closed Limit		Open/Closed	x				
EOPVC	Oxidizer Prevalve Closed Limit		Closed	x		x		
EOPVO	Oxidizer Prevalve Open Limit		Open	x		x		
ESTDCS	Start Tank Discharge Control Solenoid		On/Off	x	x	x		
RASIS-1	Augmented Spark Igniter Spark No. 1		On/Off			x		
RASIS-2	Augmented Spark Igniter Spark No. 2		On/Off			x		
RGGS-1	Gas Generator Spark No. 1		On/Off			x		
RGGS-2	Gas Generator Spark No. 2		On/Off			x		
	Flows		**gpm**					
QF-1A	Fuel	PFF	0 to 9000	x		x		
QF-2	Fuel	PFFA	0 to 9000	x	x	x		x(2)
QF-2SD	Fuel Flow Stall Approach Monitor		0 to 9000	x		x		
QFRP	Fuel Recirculation		0 to 160	x				
QO-1A	Oxidizer	POF	0 to 3000	x		x		
QO-2	Oxidizer	POFA	0 to 3000	x	x	x		
QORP	Oxidizer Recirculation		0 to 50	x			x	
	Heat Flux		**watts/Sr. cm^2**					
RTCEP(1)	Radiation Thrust Chamber Exhaust Plume		0 to 7	x				
	Position		**Percent Open**					
LFLPD(1)	Fuel Low Pressure Duct		±1 in.				x	
LFVT	Main Fuel Valve		0 to 100	x		x		

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Position		Percent Open					
LGGVT	Gas Generator Valve		0 to 100	x		x	x	
LOTBVT	Oxidizer Turbine Bypass Valve		0 to 100	x		x		
LOVT	Main Oxidizer Valve		0 to 100	x	x	x		
LPUTOP	Propellant Utilization Valve		0 to 100	x		x	x	
LSTDVT	Start Tank Discharge Valve		0 to 100	x		x		
	Pressure		psia					
PA1	Test Cell		0 to 0.5	x		x		
PA2	Test Cell		0 to 1.0	x	x			
PA3	Test Cell		0 to 5.0	x			x	
PC-1P	Thrust Chamber	CG1	0 to 1000	x			x	
PC-3	Thrust Chamber	CG1A	0 to 1000	x	x	x		
PCGG-1P	Gas Generator Chamber Pressure		0 to 1000	x	x	x		
PCGG-2	Gas Generator Chamber	GG1A	0 to 1000	x				
PFASIJ	Augmented Spark Igniter Fuel Injection		0 to 1000	x				
PFJ-1A	Main Fuel Injection	CF2	0 to 1000	x		x		
PFJ-2	Main Fuel Injection	CF2A	0 to 1000	x	x			
PFJGG-1A	Gas Generator Fuel Injection	GF4	0 to 1000	x				
PFJGG-2	Gas Generator Fuel Injection	GF4	0 to 1000	x		x		
PFM1	Fuel Jacket Inlet Manifold	CF1	0 to 2000	x				
PFPC-1A	Fuel Pump Balance Piston Cavity	PF5	0 to 1000	x				
PFPD-1P	Fuel Pump Discharge	PF3	0 to 1500	x				x (2)
PFPD-2	Fuel Pump Discharge	PF2	0 to 1500	x	x	x		
PFPI-1	Fuel Pump Inlet		0 to 100	x		x		x
PFPI-2	Fuel Pump Inlet		0 to 200	x		x	x (2)(4)	x
PFPI-3 (3)	Fuel Pump Inlet		0 to 200		x	x (3)		
PFPPSD-1	Fuel Pump Primary Seal Drain		0 to 200	x				
PFPPSD-2	Fuel Pump Primary Seal Drain		0 to 100	x				
PFPS-1P	Fuel Pump Interstage	PF6	0 to 200	x				
PFRPO	Fuel Recirculation Pump Outlet		0 to 60	x				
PFRPR	Fuel Recirculation Pump Return		0 to 50	x				
PFST-1P	Fuel Start Tank	TF1	0 to 1500	x		x		
PFST-2	Fuel Start Tank	TF1	0 to 1500	x				x
PFTSP-1	Fuel Turbine Seal Purge Line		0 to 100	x				
PFUT	Fuel Tank Ullage		0 to 100	x				
PFVI	Fuel Tank Pressurization Line Nozzle Inlet		0 to 1000	x				
PFVL	Fuel Tank Pressurization Line Nozzle Throat		0 to 1000	x				
PGGOC	Gas Generator Opening Control		0 to 500	x				
PGGVB	Gas Generator Valve Body		0 to 50	x				

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Pressure		psia					
PHECMO	Pneumatic Control Module Outlet		0 to 750	x				
PHEOP	Oxidizer Recirculation Pump Purge		0 to 150	x				
PHES	Helium Supply		0 to 5000	x				
PHET-1P	Helium Tank	NN1	0 to 3500	x		x		
PHET-2	Helium Tank	NN1	0 to 3500	x			x②	x①
PHRO-1A	Helium Regulator Outlet	NN2	0 to 750	x	x			
POBSC	Oxidizer Bootstrap Conditioning		0 to 50	x				
POBV	Gas Generator Oxidizer Bleed Valve	GO2	0 to 2000	x				
POJ-1A	Main Oxidizer Injection	CO3	0 to 1000	x		x		
POJ-2	Main Oxidizer Injection	CO3A	0 to 1000	x		x		
POJGG-1A	Gas Generator Oxidizer Injection	GO5	0 to 1000	x		x		
POJGG-2	Gas Generator Oxidizer Injection	GO5	0 to 1000	x				
POPBC-1A	Oxidizer Pump Bearing Coolant	PO7	0 to 500	x				
POPD-1P	Oxidizer Pump Discharge	PO3	0 to 1500	x				
POPD-2	Oxidizer Pump Discharge	PO2	0 to 1500	x	x	x		
POPI-1	Oxidizer Pump Inlet		0 to 100	x				x
POPI-2	Oxidizer Pump Inlet		0 to 200	x				x
POPI-3	Oxidizer Pump Inlet		0 to 100			x		
POPSC-1A	Oxidizer Pump Primary Seal Cavity	PO6	0 to 50	x				
PORPO	Oxidizer Recirculation Pump Outlet		0 to 115	x				
PORPR	Oxidizer Recirculation Pump Return		0 to 100	x				
POTI-1A	Oxidizer Turbine Inlet	TG3	0 to 200	x				
POTO-1A	Oxidizer Turbine Outlet	TG4	0 to 100	x				
POUT	Oxidizer Tank Ullage		0 to 100	x				
POVCC	Main Oxidizer Valve Closing Control		0 to 500	x	x			
POVI	Oxidizer Tank Pressurization Line Nozzle Inlet		0 to 1000	x				
POVL	Oxidizer Tank Pressurization Line Nozzle Throat		0 to 1000	x				
PPUVI-1A	Propellant Utilization Valve Inlet	PO8	0 to 1000	x				
PPUVO-1A	Propellant Utilization Valve Outlet	PO9	0 to 500	x				
PTCFJP	Thrust Chamber Fuel Jacket Purge		0 to 100	x				
PTCP	Thrust Chamber Purge		0 to 15	x				
PTPP	Turbopump and Gas Generator Purge		0 to 250	x				
	Speeds		rpm					
NFP-1P	Fuel Pump	PFV	0 to 30,000	x	x	x		
NFRP	Fuel Recirculation Pump		0 to 15,000	x				
NOP-1P	Oxidizer Pump	POV	0 to 12,000	x	x	x		
NORP	Oxidizer Recirculation Pump		0 to 15,000	x				

TABLE III-1 (Continued)

AEDC Code	Parameter	Tcp No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Temperatures		°F					
C2035 ⑦⑩	Temperature Oxidizer Bootstrap		-300 to +250	x				
C2036 ⑦	Temperature Oxidizer Bootstrap		-300 to +250	x				
C2037 ⑦	Temperature Oxidizer Bootstrap		-300 to +250	x				
TA1	Test Cell (North)		-50 to +800	x				
TA2	Test Cell (East)		-50 to +800	x				
TA3	Test Cell (South)		-50 to +800	x				
TA4	Test Cell (West)		-50 to +800	x				
TAIP-1A	Auxiliary Instrument Package		-300 to +200	x				
TBPM	Bypass Manifold		-325 to +200	x				
TBSC	Oxidizer Bootstrap Conditioning		-350 to +150	x				
TECP-1P	Electrical Controls Package	NST1A	-300 to +200	x			x	
TFASIJ	Augmented Spark Igniter Fuel Injection	IFT1	-425 to +100	x		x		
TFASIL-1	Augmented Spark Igniter Line		-300 to +300	x				
TFASIL-2	Augmented Spark Igniter Line		-300 to +300	x				
TFBV-1A	Fuel Bleed Valve	GFT1	-425 to -375	x				
TFD-1	Fire Detection		0 to 1000	x				
TFJ-1P	Main Fuel Injection	CFT2	-425 to +250	x	x ④	x		
TFPD-1P	Fuel Pump Discharge	PFT1	-425 to -400	x	x	x		
TFPD-2	Fuel Pump Discharge	PFT1	-425 to -400	x				
TFPDD	Fuel Pump Discharge Duct		-320 to +300	x				
TFPI-1	Fuel Pump Inlet		-425 to -400	x			x ①	x
TFPI-2	Fuel Pump Inlet		-425 to -400	x			x ②⑥	x
TFPI-3	Fuel Pump Inlet		-425 to -400	x				
TFPPSD-1	Fuel Pump Primary Seal Drain		-425 to +100	x				
TFPSP-1	Fuel Pump Seal Purge		-425 to +100	x				
TFRPO	Fuel Recirculation Pump Outlet		-425 to -410	x				
TFRPR	Fuel Recirculation Pump Return Line		-425 to -250	x				
TFRT-1	Fuel Tank		-425 to -410	x				
TFRT-3	Fuel Tank		-425 to -410	x				
TFST-1P	Fuel Start Tank	TFT1	-350 to +100	x				
TFST-2	Fuel Start Tank	TFT1	-350 to +100	x				x
TFTD-1	Fuel Turbine Discharge Duct		-200 to +800	x				
TFTD-2	Fuel Turbine Diacharge Duct		-200 to +1000	x			x	
TFTD-3	Fuel Turbine Diacharge Duct		-200 to -1000	x			x	
TFTD-3R ④	Fuel Turbine Discharge Line		-200 to -900	x				
TFTD-4	Fuel Turbine Discharge Duct		-200 to +1000	x				
TFTD-5	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-6	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-7	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-8	Fuel Turbine Discharge Duct		-200 to +1400	x			x	
TFTI-1P ④	Fuel Turbine Inlet	TFT1	0 to 1800	x			x ④	
TFTO	Fuel Turbine Outlet	TFT2	0 to 1800	x				

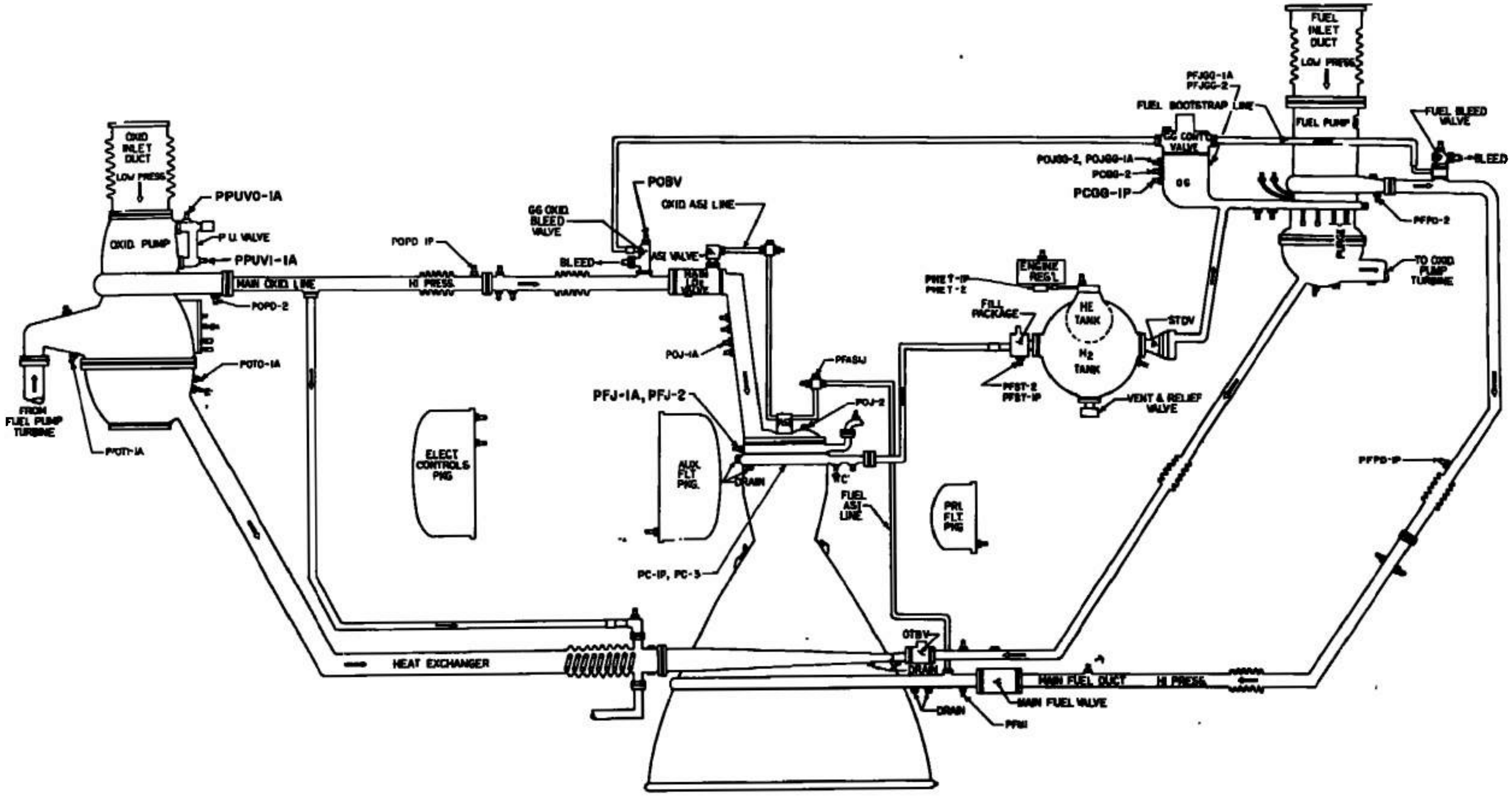
TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TFTSD-1	Fuel Turbine Seal Drain Line		-300 to +100	x				
TGGO-1A	Gas Generator Outlet	GGT1	0 to 1800	x		x	x[5]	
TGGVRS	Gas Generator Valve Retaining Screw		-100 to +100	x			x	
THET-1P	Helium Tank	NNT1	-350 to +100	x			x[2]	x[1]
TMFV-1[7]	Main Fuel Valve		-100 to +300	x				
TMFV-2[7]	Main Fuel Valve		-100 to +300	x				
TNODP	Liquid Oxygen Dome Purge		0 to -300	x				
TOBS-1	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2	Oxidizer Bootstrap Line		-300 to -250	x				
TOBS-2A	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2B	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-3[8]	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-4	Oxidizer Bootstrap Line		-300 to +250	x				
TOBV-1A	Oxidizer Bleed Valve	GOT2	-300 to -250	x				
TOPB-1A	Oxidizer Pump Bearing Coolant	POT4	-300 to -250	x				
TOPD-1P	Oxidizer Pump Discharge	POT3	-300 to -250	x	x	x	x	
TOPD-2	Oxidizer Pump Discharge	POT3	-300 to -250	x				
TOPI-1	Oxidizer Pump Inlet		-310 to -270	x				x
TOPI-2	Oxidizer Pump Inlet		-310 to -270	x				x
TORPO	Oxidizer Recirculation Pump Outlet		-300 to -250	x				
TORPR	Oxidizer Recirculation Pump Return		-300 to -140	x				
TORT-1	Oxidizer Tank		-300 to -287	x				
TORT-1B	Oxidizer Tank		-300 to -287	x				
TORT-3	Oxidizer Tank		-300 to -287	x				
TOTBV-1[8]	Oxidizer Turbine Bypass Valve		-100 to +300	x				
TOTBV-2[8]	Oxidizer Turbine Bypass Valve		-100 to +300	x				
TOTI-1P	Oxidizer Turbine Inlet	TGT3	0 to 1200	x			x	
TOTO-1P	Oxidizer Turbine Outlet	TGT4	0 to 1000	x				
TOVL	Oxidizer Tank Pressurization Line Nozzle Throat		-300 to +100	x				
TPCC	Prechill Controller		-425 to -300	x				
TPIP-1P	Primary Instrument Package		-300 to +200	x				
TSC2-1	Thrust Chamber Skin		-300 to +500	x				
TSC2-2	Thrust Chamber Skin		-300 to +500	x				
TSC2-3	Thrust Chamber Skin		-300 to +500	x				
TSC2-4	Thrust Chamber Skin		-300 to +500	x				
TSC2-5	Thrust Chamber Skin		-300 to +500	x				
TSC2-6	Thrust Chamber Skin		-300 to +500	x				
TSC2-7	Thrust Chamber Skin		-300 to +500	x				
TSC2-8	Thrust Chamber Skin		-300 to +500	x				
TSC2-9	Thrust Chamber Skin		-300 to +500	x				

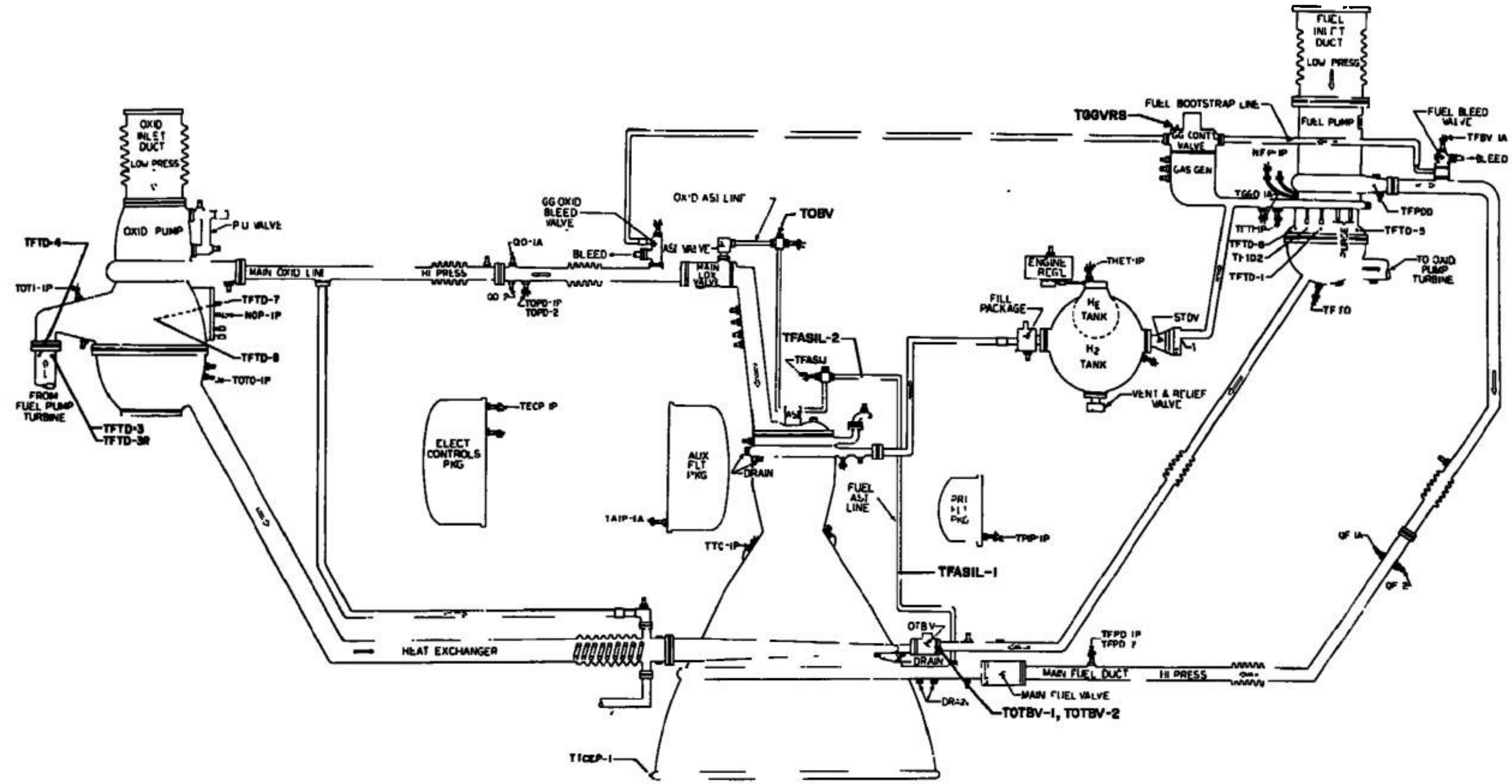
TABLE III-1 (Concluded)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Temperatures		**°F**					
TSC2-10	Thrust Chamber Skin		-300 to +500	x				
TSC2-11	Thrust Chamber Skin		-300 to +500	x				
TSC2-12	Thrust Chamber Skin		-300 to +500	x				
TSC2-13	Thrust Chamber Skin		-300 to +500	x			x	
TSC2-14	Thrust Chamber Skin		-300 to +500	x				
TSC2-15	Thrust Chamber Skin		-300 to +500	x				
TSC2-16	Thrust Chamber Skin		-300 to +500	x				
TSC2-17	Thrust Chamber Skin		-300 to +500	x				
TSC2-18	Thrust Chamber Skin		-300 to +500	x				
TSC2-19	Thrust Chamber Skin		-300 to +500	x				
TSC2-20	Thrust Chamber Skin		-300 to +500	x				
TSC2-21	Thrust Chamber Skin		-300 to +500	x				
TSC2-22	Thrust Chamber Skin		-300 to +500	x				
TSC2-23	Thrust Chamber Skin		-300 to +500	x				
TSC2-24	Thrust Chamber Skin		-300 to +500	x				
TSOVAL-1	Oxidizer Valve Closing Control Line		-200 to +100	x				
TSOVC-1	Oxidizer Valve Actuator Cap		-325 to +150	x			x	
TSTC	Start Tank Conditioning		-350 to +150	x				
TSTDVOC	Start Tank Discharge Valve Opening Control Port		-350 to +100	x			x	
TTC-1P	Thrust Chamber Jacket (Control)	CS1	-425 to +500	x			x	
TTC-2⑦	Thrust Chamber Jacket (Control)	CS1A	-425 to +500	x			x	
TTCEP-1	Thrust Chamber Exit		-425 to +500	x				
TTPP	Turbopump Purge		-150 to +150	x			x⑤	
	Vibrations		**g's**					
UFPR	Fuel Pump Radial 90 deg		±200		x	x②		
UOPR	Oxidizer Pump Radial 90 deg		±200		x			
UTCD-1	Thrust Chamber Dome		±500		x	x		
UTCD-2	Thrust Chamber Dome		±500		x	x		
UTCD-3	Thrust Chamber Dome		±500		x	x		
U1VSC	No. 1 Vibration Safety Counts		On/Off			x		
U2VSC	No. 2 Vibration Safety Counts		On/Off			x		
	Voltage		**volts**					
VCB	Control Bus		0 to 36	x		x		
VIB	Ignition Bus		0 to 36	x		x		
VIDA	Ignition Detect Amplifier		9 to 16	x		x		
VPUTEP	Propellant Utilization Valve Excitation		0 to 5	x				

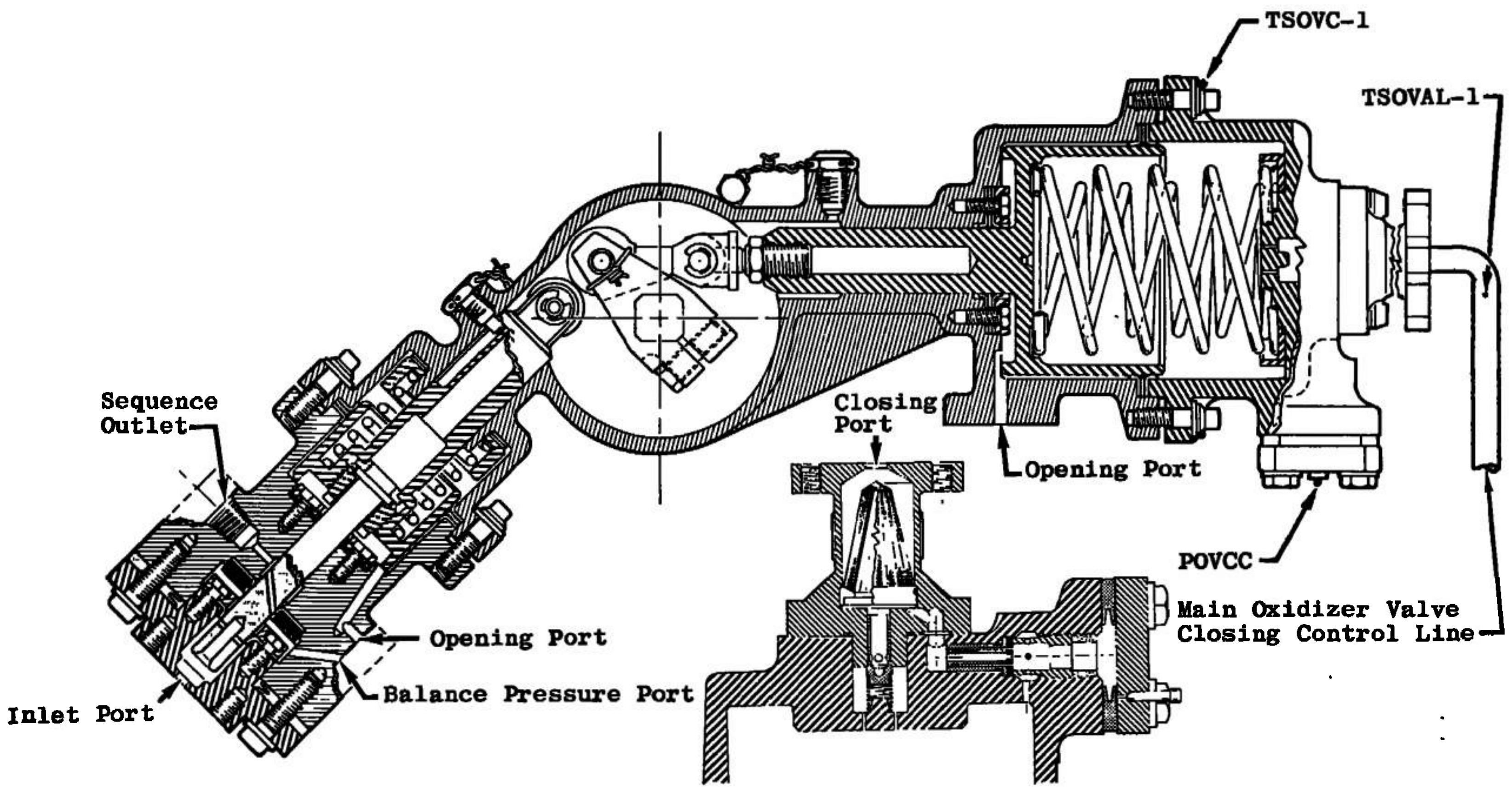
①Applies to test 28 only.
②Does not apply to test 28.
③Applies to tests after test 29.
④Does not apply to tests after test 29.
⑤Applies to tests after test 30.
⑥Does not apply to tests after test 30.
⑦Applies to tests after test 31.
⑧Does not apply to tests after test 31.
⑨Applies to tests after test 32.
⑩Does not apply to tests after test 32.



a. Engine Pressure Tap Locations
Fig. III-1 Instrumentation Locations

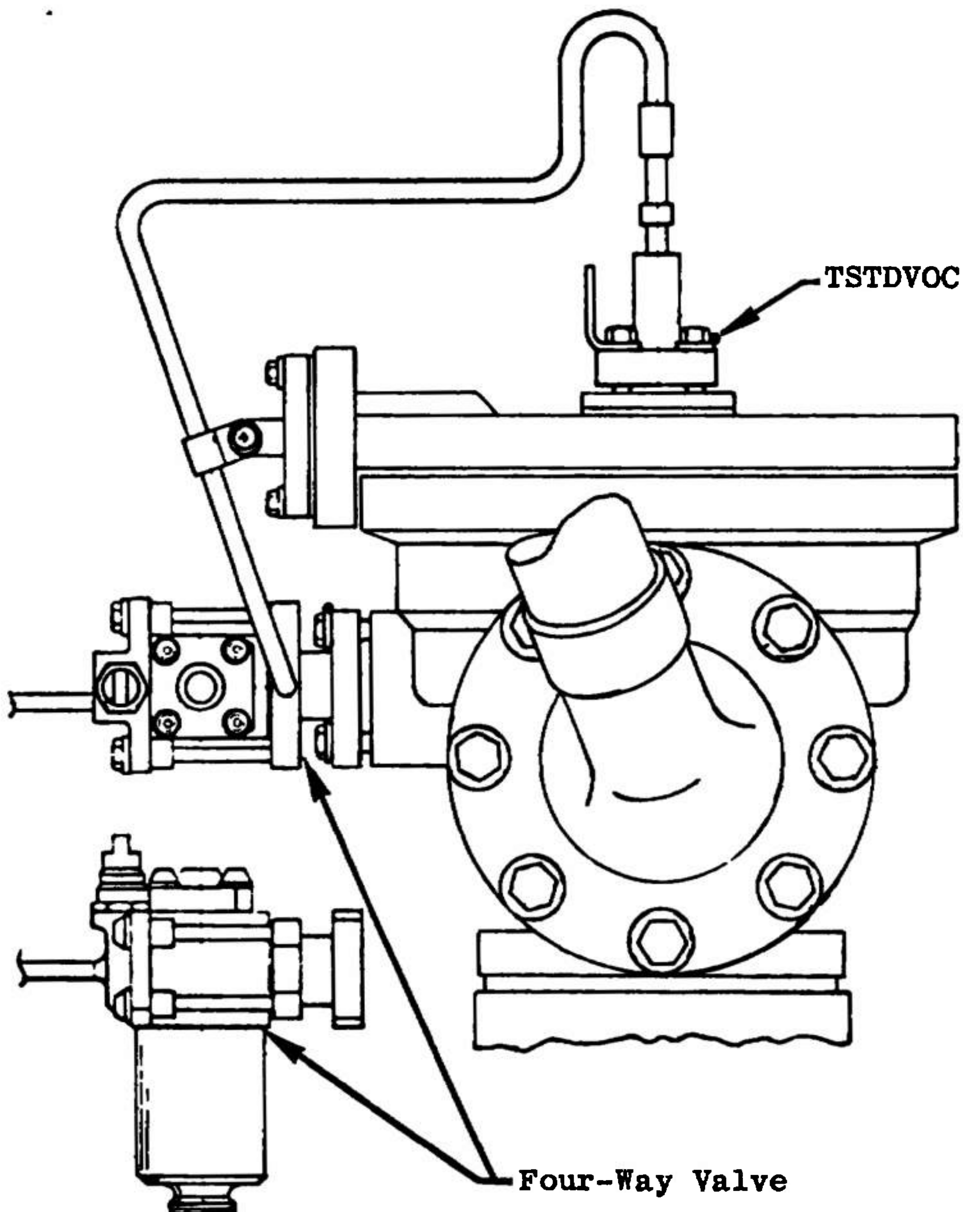


b. Engine Temperature, Flow, and Speed Instrumentation Locations
Fig. III-1 Continued

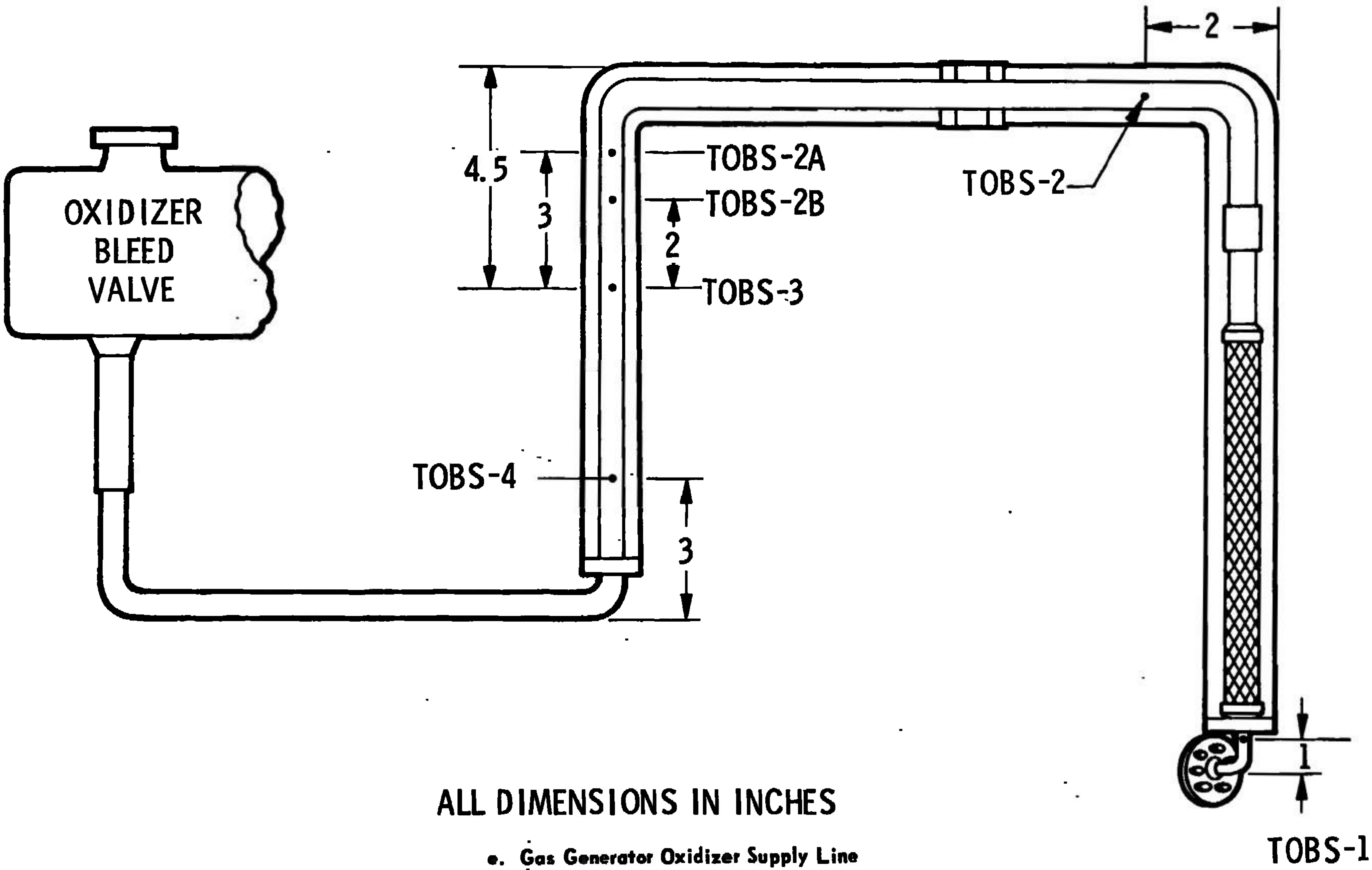


c. Main Oxidizer Valve

Fig. III-1 Continued

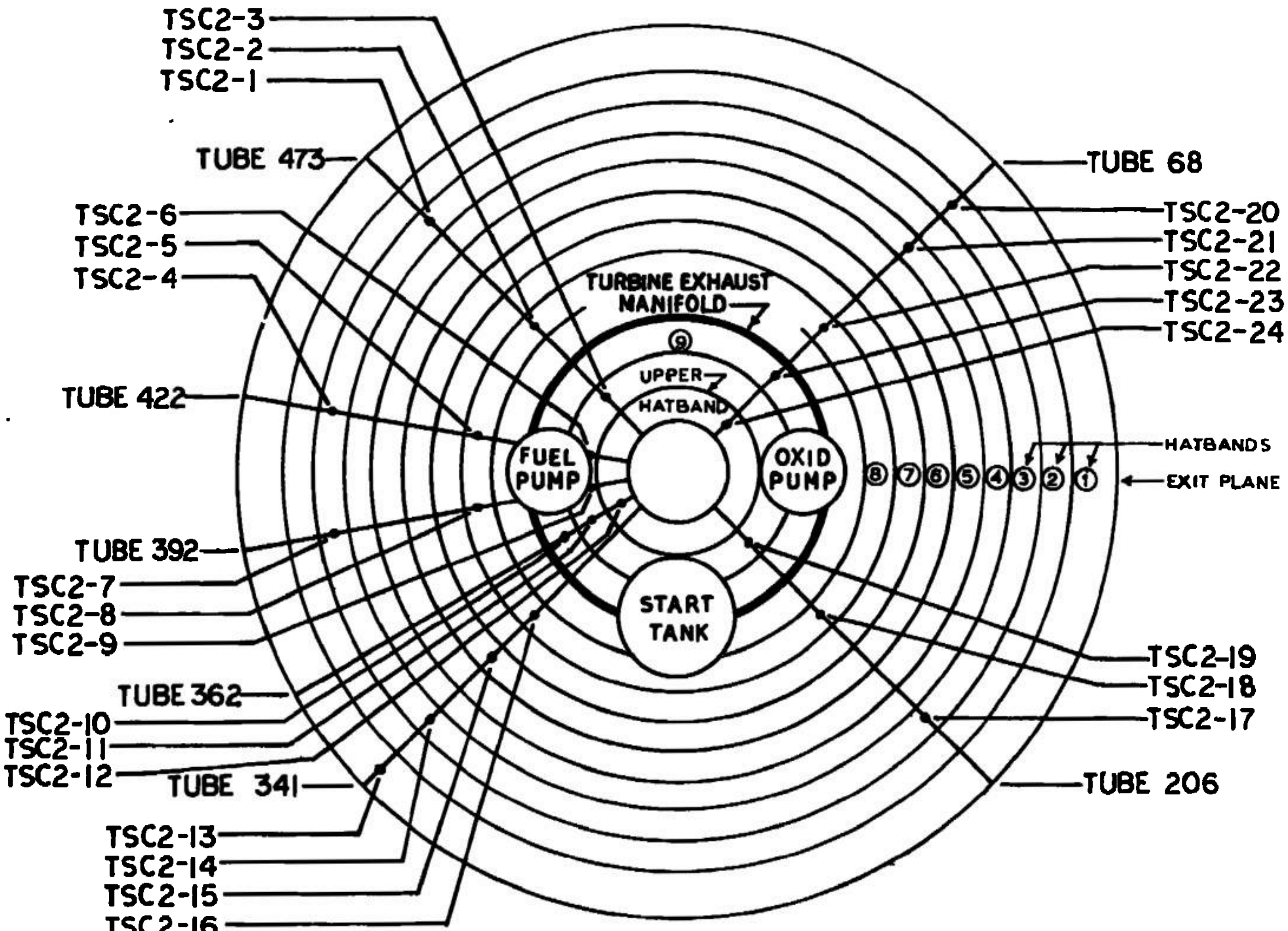


d. Start Tank Discharge Valve
Fig. III-1 Continued



e. Gas Generator Oxidizer Supply Line

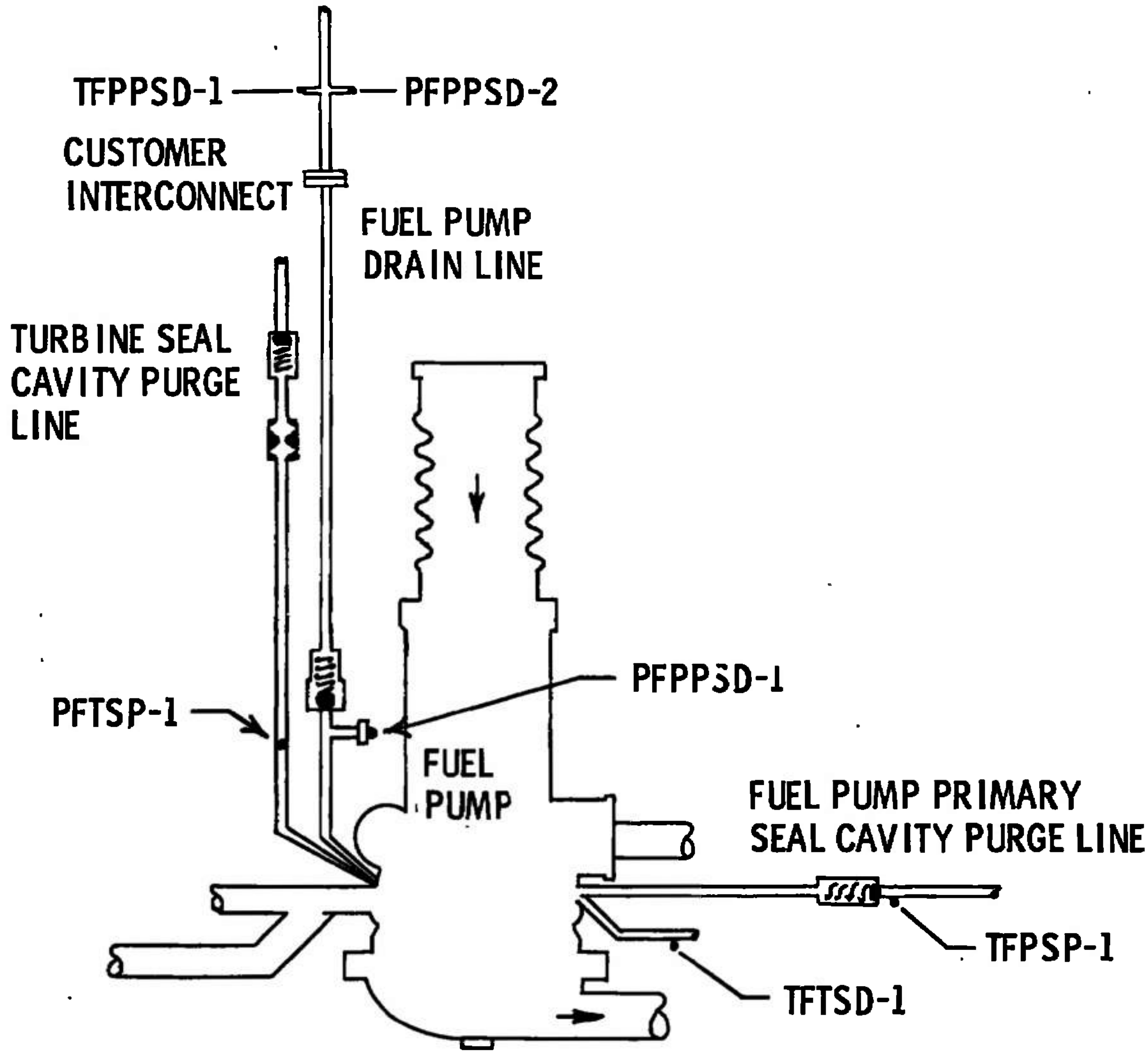
Fig. III-1 Continued



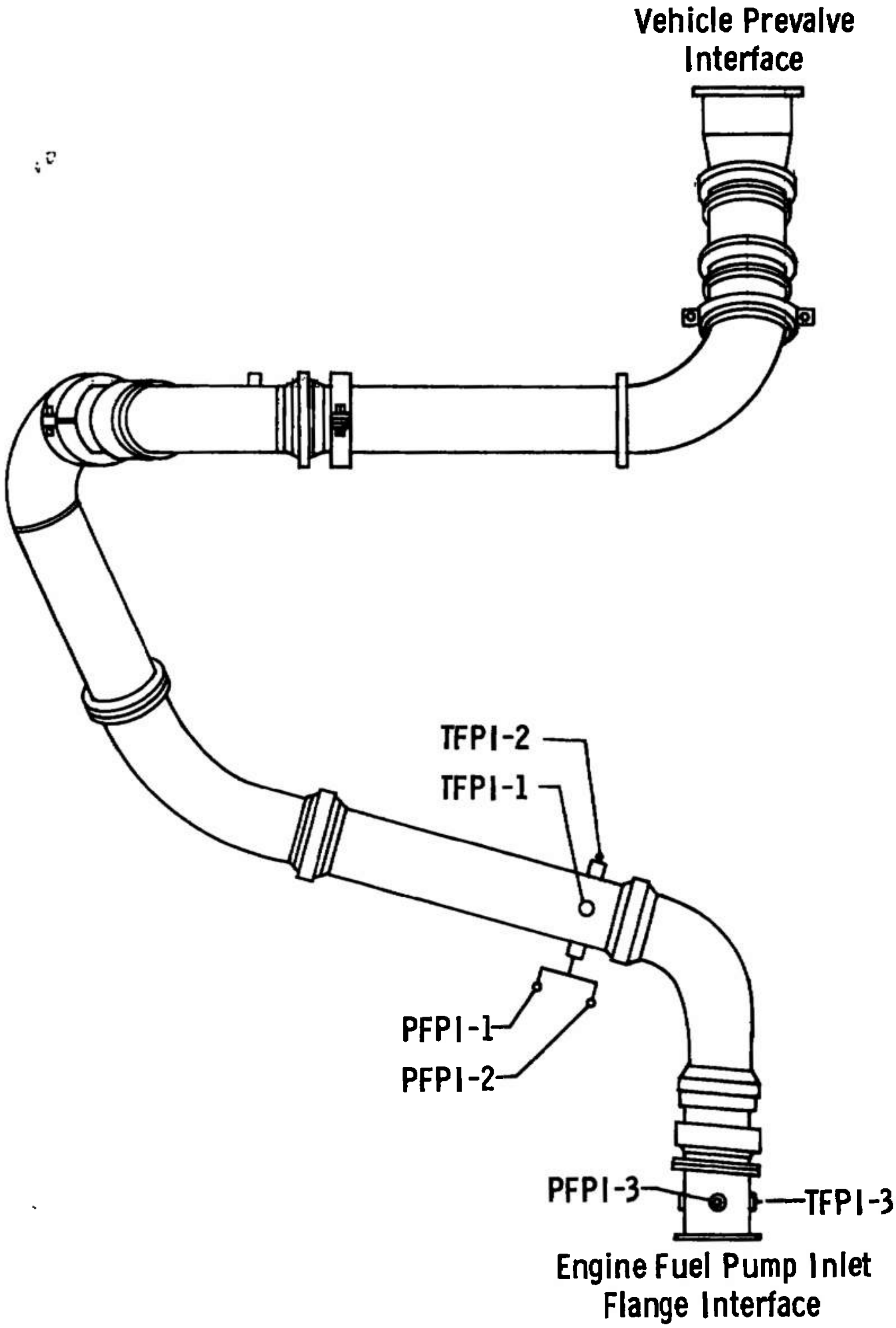
VIEW LOOKING AFT

f. Thrust Chamber

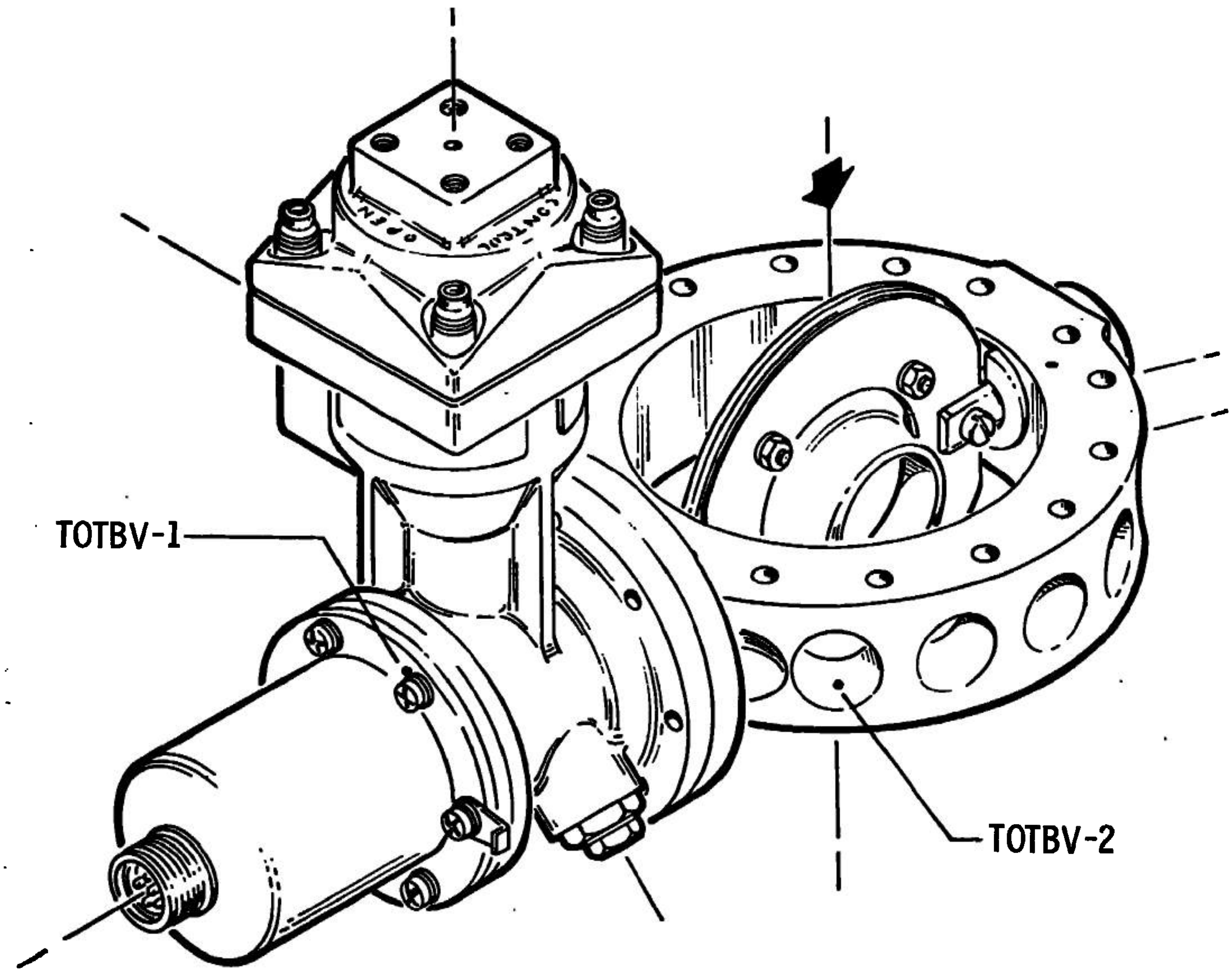
Fig. III-1 Continued



g. Fuel Pump and Turbine Purge and Drain Line
Fig. III-1 Continued



h. Fuel Low Pressure Duct
Fig. III-1 Continued



i. Oxidizer Turbine Bypass Valve

Fig. III-1 Concluded

APPENDIX IV
METHODS OF CALCULATION (PERFORMANCE PROGRAM)

TABLE IV-1
PERFORMANCE PROGRAM DATA INPUTS

Item No.	Parameter
1	Thrust Chamber (Injector Face) Pressure, psia
2	Thrust Chamber Fuel and Oxidizer Injection Pressures, psia
3	Thrust Chamber Fuel Injection Temperature, °F
4	Fuel and Oxidizer Flowmeter Speeds, Hz
5	Fuel and Oxidizer Engine Inlet Pressures, psia
6	Fuel and Oxidizer Pump Discharge Pressures, psia
7	Fuel and Oxidizer Engine Inlet Temperatures, °F
8	Fuel and Oxidizer (Main Valves) Temperatures, °F
9	Propellant Utilization Valve Center Tap Voltage, volts
10	Propellant Utilization Valve Position, volts
11	Fuel and Oxidizer Pump Speeds, rpm
12	Gas Generator Chamber Pressure, psia
13	Gas Generator (Bootstrap Line at Bleed Valve) Temperature, °F
14	Fuel* and Oxidizer Turbine Inlet Pressure, psia
15	Oxidizer Turbine Discharge Pressure, psia
16	Fuel and Oxidizer Turbine Inlet Temperature, °F
17	Oxidizer Turbine Discharge Temperature, °F

*At AEDC, fuel turbine inlet pressure is calculated from gas generator chamber pressure.

NOMENCLATURE

A	Area, in.^{2}
B	Horsepower, hp
C*	Characteristic velocity, ft/sec
C_p	Specific heat at constant pressure, Btu/lb/°F
D	Diameter, in.
H	Head, ft
h	Enthalpy, Btu/lb_m
M	Molecular weight
N	Speed, rpm
P	Pressure, psia
$\dot{Q}$	Flow rate, gpm
R	Resistance, sec^2/ft^3-in.^{2}
r	Mixture ratio
T	Temperature, °F
TC*	Theoretical characteristic velocity, ft/sec
W	Weight flow, lb/sec
Z	Pressure drop, psi
β	Ratio
γ	Ratio of specific heats
η	Efficiency
θ	Degrees
ρ	Density, lb/ft^3

SUBSCRIPTS

A	Ambient
AA	Ambient at thrust chamber exit
B	Bypass nozzle

BIR	Bypass nozzle inlet (Rankine)
BNI	Bypass nozzle inlet (total)
C	Thrust chamber
CF	Thrust chamber, fuel
CO	Thrust chamber, oxidizer
CV	Thrust chamber, vacuum
E	Engine
EF	Engine fuel
EM	Engine measured
EO	Engine oxidizer
EV	Engine, vacuum
e	Exit
em	Exit measured
F	Thrust
FIT	Fuel turbine inlet
FM	Fuel measured
FY	Thrust, vacuum
f	Fuel
G	Gas generator
GF	Gas generator fuel
GO	Gas generator oxidizer
H1	Hot gas duct No. 1
H1R	Hot gas duct No. 1 (Rankine)
H2R	Hot gas duct No. 2 (Rankine)
IF	Inlet fuel
IO	Inlet oxidizer
ITF	Isentropic turbine fuel
ITO	Isentropic turbine oxidizer
N	Nozzle
NB	Bypass nozzle (throat)

NV	Nozzle, vacuum
O	Oxidizer
OC	Oxidizer pump calculated
OF	Outlet fuel pump
OFIS	Outlet fuel pump isentropic
OM	Oxidizer measured
OO	Oxidizer outlet
PF	Pump fuel
PO	Pump oxidizer
PUVO	Propellant utilization valve oxidizer
RNC	Ratio bypass nozzle, critical
SC	Specific, thrust chamber
SCV	Specific thrust chamber, vacuum
SE	Specific, engine
SEV	Specific, engine vacuum
T	Total
T_O	Turbine oxidizer
TEF	Turbine exit fuel
TEFS	Turbine exit fuel (static)
TF	Fuel turbine
TIF	Turbine inlet fuel (total)
TIFM	Turbine inlet, fuel, measured
TIFS	Turbine inlet fuel isentropic
TIO	Turbine inlet oxidizer
t	Throat
V	Vacuum
v	Valve
XF	Fuel tank repressurant
XO	Oxidizer tank repressurant

PERFORMANCE PROGRAM EQUATIONS

MIXTURE RATIO

Engine

$$r_E = \frac{W_{EO}}{W_{EF}}$$

$$W_{EO} = W_{OM} - W_{XO}$$

$$W_{EF} = W_{FM} - W_{XF}$$

$$W_E = W_{EO} + W_{EF}$$

Thrust Chamber

$$r_C = \frac{W_{CO}}{W_{CF}}$$

$$W_{CO} = W_{OM} - W_{XO} - W_{GO}$$

$$W_{CF} = W_{FM} - W_{XF} - W_{GF}$$

$$W_{XO} = 0.9 \text{ lb/sec}$$

$$W_{XF} = 2.1 \text{ lb/sec}$$

$$W_{GO} = W_T - W_{GF}$$

$$W_{GF} = \frac{W_T}{1 + r_G}$$

$$W_T = \frac{P_{TIF}\ A_{TIF}\ K_7}{TC^*_{TIF}}$$

$$K_7 = 32.174$$

$$W_C = W_{CO} + W_{CF}$$

CHARACTERISTIC VELOCITY

Thrust Chamber

$$C^* = \frac{K_7\ P_c\ A_t}{W_C}$$

$$K_7 = 32.174$$

DEVELOPED PUMP HEAD

Flows are normalized by using the following inlet pressures, temperatures, and densities.

$$P_{IO} = 39 \text{ psia}$$
$$P_{IF} = 30 \text{ psia}$$
$$\rho_{IO} = 70.79 \text{ lb/ft}^3$$
$$\rho_{IF} = 4.40 \text{ lb/ft}^3$$
$$T_{IO} = -295.212\,^\circ F$$
$$T_{IF} = -422.547\,^\circ F$$

Oxidizer

$$H_O = K_4 \left(\frac{P_{OO}}{\rho_{OO}} - \frac{P_{IO}}{\rho_{IO}}\right)$$
$$K_4 = 144$$
$$\rho = \text{National Bureau of Standards Values } f\,(P,T)$$

Fuel

$$H_f = 778.16\, \Delta h_{OFIS}$$
$$\Delta h_{OFIS} = h_{OFIS} - h_{IF}$$
$$h_{OFIS} = f(P,T)$$
$$h_{IF} = f(P,T)$$

PUMP EFFICIENCIES

Fuel, Isentropic

$$\eta_f = \frac{h_{OFIS} - h_{IF}}{h_{OF} - h_{IF}}$$
$$h_{OF} = f(P_{OF}, T_{OF})$$

Oxidizer, Isentropic

$$\eta_O = \eta_{OC}\, Y_O$$
$$\eta_{OC} = K_{40} \left(\frac{Q_{PO}}{N_O}\right)^2 + K_{50} \left(\frac{Q_{PO}}{N_O}\right) + K_{60}$$
$$K_{40} = 5.0526$$
$$K_{50} = 3.8611$$
$$K_{60} = 0.0733$$
$$Y_O = 1.000$$

TURBINES

Oxidizer, Efficiency

$$\eta_{TO} = \frac{B_{TO}}{B_{ITO}}$$

$$B_{TO} = K_5 \frac{W_{PO}\ H_O}{\eta_O}$$

$$K_5 = 0.001818$$

$$W_{PO} = W_{OM} + W_{PUVO}$$

$$W_{PUVO} = \sqrt{\frac{Z_{PUVO}\ \rho_{OO}}{R_v}}$$

$$Z_{PUVO} = A + B\ (P_{OO})$$

$$A = -1597$$

$$B = 2.3818$$

$$\text{IF } P_{OO} \geq 1010 \text{ Set } P_{OO} = 1010$$

$$\ell n\, Rv = A_3 + B_3\,(\theta_{PUVO}) + C\,(\theta_{PUVO})^3 + D_3\,(e)^{\frac{\theta_{PUVO}}{7}} + E_3\,(\theta_{PUVO})\,(e)^{\frac{\theta_{PUVO}}{7}} + F_3 \left[(e)^{\frac{\theta_{PUVO}}{7}}\right]^2$$

$$A_3 = 5.5659 \times 10^{-1}$$

$$B_3 = 1.4997 \times 10^{-2}$$

$$C_3 = 7.9413 \times 10^{-6}$$

$$D_3 = 1.2343$$

$$E_3 = -7.2554 \times 10^{-2}$$

$$F_3 = 5.0691 \times 10^{-2}$$

Fuel, Efficiency

$$\eta_{TF} = \frac{B_{TF}}{B_{ITF}}$$

$$B_{ITF} = K_{10}\ \Delta h_f\ W_T$$

$$\Delta h_f = h_{TIF} - h_{TEF}$$

$$B_{TF} = B_{PF} = K_5 \left(\frac{W_{PF}\ H_f}{\eta_f}\right)$$

$$W_{PF} = W_{FM}$$

$$K_{10} = 1.4148$$

$$K_5 = 0.001818$$

Oxidizer, Developed Horsepower

$$B_{TO} = B_{PO} + K_{56}$$

$$B_{PO} = K_5 \frac{W_{PO} H_O}{\eta_O}$$

$$K_{56} = -15$$

Fuel, Developed Horsepower

$$B_{TF} = B_{PF}$$

$$B_{PF} = K_5 \frac{W_{PF} H_f}{\eta_f}$$

$$W_{PF} = W_{FM}$$

Fuel, Weight Flow

$$W_{TF} = W_T$$

Oxidizer, Weight Flow

$$W_{TO} = W_T - W_B$$

$$W_B = \left[\frac{2K_7 \gamma_{H2}}{\gamma_{H2}-1} (P_{RNC})^{\frac{2}{\gamma_{H2}}} \right]^{1/2} \left[1 - (P_{RNC})^{\frac{\gamma_{H2}-1}{\gamma_{H2}}} \right] \frac{A_{NB} P_{BNI}}{(R_{H2} T_{BIR})^{1/2}}$$

$$P_{RNC} = f(\beta_{NB}, \gamma_{H2})$$

$$\beta_{NB} = \frac{D_{NB}}{D_B}$$

$$\gamma_{H2}, M_{H2} = f(T_{H2R}, r_G)$$

$$A_{NB} = K_{13} D_{NB}$$

$$K_{13} = 0.7854$$

$$T_{BIR} = T_{TIO} + 460$$

$$P_{BNI} = P_{TEFS}$$

$$P_{TEFS} = \text{Iteration of } P_{TEF}$$

$$P_{TEF} = P_{TEFS} \left[1 + K_8 \left(\frac{W_T}{P_{TEFS}} \right)^2 \frac{T_{H2R}}{D^4_{TEF} M_{H2}} \left(\frac{\gamma_{H2}-1}{\gamma_{H2}} \right) \right]^{\frac{\gamma_{H2}}{\gamma_{H2}-1}}$$

$$K_8 = 38.8983$$

GAS GENERATOR

Mixture Ratio

$$r_G = D_1 (T_{H1})^3 + C_1 (T_{H1})^2 + B_1 (T_{H1}) + A_1$$

$$A_1 = 0.2575$$

$$B_1 = 5.586 \times 10^{-4}$$

$$C_1 = -5.332 \times 10^{-9}$$

$$D_1 = 1.1312 \times 10^{-11}$$

$$T_{H1} = T_{TIFM}$$

Flows

$$TC^*_{TIF} = D_2 (T_{H1})^3 + C_2 (T_{H1})^2 + B_2 (T_{H1}) + A_2$$

$$A_2 = 4.4226 \times 10^3$$

$$B_2 = 3.2267$$

$$C_2 = -1.3790 \times 10^{-3}$$

$$D_2 = 2.6212 \times 10^{-7}$$

$$P_{TIF} = P_{TIFS}\left[1 + K_8\left(\frac{W_T}{P_{TIFS}}\right)^2 \cdot \frac{T_{H1R}}{D^4_{TIF}\, M_{H1}} \quad \frac{\gamma_{H1} - 1}{\gamma_{H1}}\right]^{\frac{\gamma_{H1}}{\gamma_{H1}-1}}$$

$$K_8 = 38.8983$$

Note: P_{TIF} is determined by iteration.

$$T_{H1R} = T_{TIF}$$

$$M_{H1}, \gamma_{H1}, C_p, r_{H1} = f\,(T_{H1R}, r_G)$$

APPENDIX V
METHODS OF CALCULATION (HEAD RISE AND FLOW COEFFICIENTS)

FLOW COEFFICIENT, ϕ

$$\phi \sim \frac{V_f}{V_T}$$

where V_f = Absolute fluid velocity at inducer inlet, ft/sec

$$V_f = \frac{Q}{(448.9)\ A}$$

Q = Flow rate, gpm

A = Inducer annulus area, ft^2 (specified as 0.2856 ft^2 by Rocketdyne)

$$V_f = \frac{Q}{128.2}$$

and V_T = Absolute velocity of inducer rotor tip, ft/sec

$$V_T = \left(\frac{\pi}{60}\right)(D_T)\ (N)$$

N = Pump speed, rpm

D_T = Inducer rotor tip diameter, ft (specified as 0.653 ft by Rocketdyne)

Therefore,

$$\phi = \left[\frac{1}{(128.2)\ (0.0340)}\right]\ \frac{Q}{N}$$

$$\phi = 0.2291\ \frac{Q}{N}$$

HEAD RISE COEFFICIENT

$$\Psi \sim \frac{H}{(V_{T^1})^2} = \frac{(H)\,(g)}{(V_{T^1})^2}$$

where H = Total pump head rise, ft

g = 32.174 ft/sec^2

and V_{T^1} = Absolute velocity of pump rotor tip, ft/sec

$$V_{T^1} = \left(\frac{\pi}{60}\right)(D_{T^1})\ (N)$$

N = Pump speed, rpm

D_{T^1} = Pump rotor tip diameter, ft (specified as 0.6043 ft by Rocketdyne)

$$V_{T^1} = 0.03164N$$

Therefore,

$$\Psi = \left[\frac{32.174}{(0.03164)^2}\right]\ \frac{H}{N^2}$$

$$\Psi = 32{,}150\,\frac{H}{N^2}$$

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13 ABSTRACT

Twenty-four firings and two fuel lead tests of the Rocketdyne J-2 rocket engine were conducted during test periods J4-1801-28 through J4-1801-33 between February 15 and March 20, 1968, in Test Cell J-4 of the Large Rocket Facility. This testing was in support of the J-2 engine application to the S-II stage of the Saturn V vehicle. The firings were accomplished at pressure altitudes ranging from 55,000 to 116,000 ft at engine start. The primary objective of these firings was to investigate fuel pump operation under conditions of lower than minimum engine model specification fuel pump net positive suction head and maximum thrust chamber fuel flow resistance utilizing an S-II stage center engine configuration fuel low pressure duct designed to simulate the fluid dynamic characteristics experienced during flight. Engine components were thermally conditioned to temperatures as expected during flight. Engine operation appeared to be satisfactory. The total accumulated firing duration for the six test periods was 190 sec. The total firing duration of this engine at AEDC through test period J4-1801-33 is 940 sec, resulting from 79 engine firings.

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1. Missiles -- Saturn
2 Rocket motors -- J-2
4 " " -- Performance

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